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The Effect of Time and Temperature of Cooking on the Palatability and Cooking Losses of Frozen Atlantic Codfish Fillets[1,2]

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ABSTRACT

Methods of preparing codfish fillets were developed to determine whether baking at 300°F or 500°F was the more suitable temperature to produce optimum quality of the final product. Different methods of thawing, and cooking covered and uncovered were evaluated by a trained test panel. There appeared to be no significant differences between the final products cooked at the lower and higher temperatures.

INTRODUCTION

Fish is an inexpensive, nutritious food, readily available to Canadian consumers, yet, according to Department of Fisheries reports there is a yearly surplus of fish. It is marketed fresh, frozen, canned, smoked, pickled, salted, dried, and in other forms; but in spite of this variety, comparatively few reports of studies which deal with the preparation of fish as a palatable food are to be found in the literature. All types of fish, whether marine or freshwater, carry a potentially valuable contribution to good nutrition in their high-quality protein, minerals and vitamins, and relatively low fat content as compared with beef and pork (Dept. Nat. Health and Welfare, 1951), their low cholesterol content (McLester–Darby, 1956), and their important amounts of the essential fatty acids (Hilditch, 1940, pp. 34–35, 38–40).

Charley (1952) investigated the effects of oven temperature on the cooking losses and palatability of baked salmon steaks, and Charley and Goertz (1958) extended this work by using larger pieces of salmon. Osterhaug and MacFarlane (1955) and Elgin *et al.* (1957) reported on the cooking of frozen halibut steaks. Frozen Atlantic cod fillets were chosen for the present study. The fillets were baked at low and high oven temperatures, various thawing procedures were tested, and the effect of baking the fillets covered and uncovered was studied.

[1]Received for publication June 23, 1958.
[2]This paper was prepared in fulfilment of a contract with the Fisheries Research Board of Canada.

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EXPERIMENTAL PROCEDURE

Method of Sampling. Commercial frozen codfish fillets of approximately 1-pound (450 g) weight were maintained in a freezer at 5 to 10°F (−15 to −12°C). Preliminary experiments, in which frozen fillets were used to determine "doneness", suggested that the results were affected by the excess moisture which surrounded the frozen fillets. In order to eliminate some of this error, the following method of sampling was developed: Paired samples A and B of similar surface area and weight (150 ± 8 g) were obtained by cutting the fillet in half laterally after trimming off about ½ inch (1 cm) of its periphery (Fig. 1). This treatment

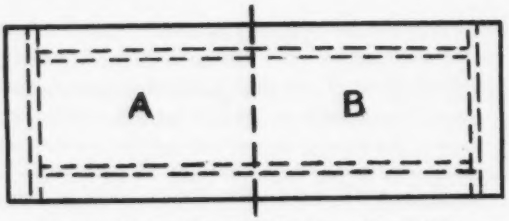

FIG. 1. Trimming and bisection of frozen fillet.

excluded the areas which might have been principally affected by external water inevitably present during commercial washing, cleaning and freezing. The samples were baked as follows: Sample A was placed on a piece of weighed aluminum foil on an aluminum baking sheet and cooked in a thermostatically controlled oven at 300°F (150°C). Sample B was treated similarly and baked at 500°F (260°C).

Doneness. Experiments were carried out to determine optimum doneness (ivory white flesh with firm but tender moist flakes) using paired samples baked at 300 and 500°F directly from the frozen state for various lengths of time. Baking at 300°F for 70 minutes and at 500°F for 25 minutes were found to produce the desired characteristics. When thawed samples were later tested, the time was adjusted to 60 minutes at 300°F and 20 minutes at 500°F, as a result of taste panel scores.

Organoleptic Tests. Coded specimens of each cooked sample were evaluated by a panel of five judges who had been previously trained in tasting codfish. The fillet was cooled to room temperature after removal from the oven, and divided for scoring in such a way that the presence of outside edges would not reveal the cooking procedure. Individual judgment of six characteristics—colour, moistness, texture, tenderness, flavour and general acceptability—was recorded on a score sheet. A maximum of three points was allowed for each category and thus the highest possible rating, 18, was equivalent to 100%. The various scores are expressed in percentage for comparison.

Moisture Determination. The moisture content of each pair of cooked samples was determined, using the A.O.A.C. (1955, p. 394) method. This value is expressed as percentage of the cooked weight.

Losses. Loss of weight during preparation of the cooked product was due to (*a*) evaporation of moisture from the fish during cooking procedure, and (*b*) the squeezing out of a moist white coagulum which collected on the aluminum foil during the time in the oven. This was assumed to be protein denatured by the heat, and was not served to the taste panel. In one phase of the experiment, paired samples were placed in sealed pliofilm bags[3] and allowed to thaw under different conditions before putting in the oven. The liquid which accumulated during this procedure became an additional source of weight loss and was designated "thawing drip" to distinguish it from the moist white coagulum or "oven drip".

Methods of Thawing. Six defrosting procedures were tested. These were: (*a*) overnight thawing at room temperature (74°F, 23°C), (*b*) 4 hours at room temperature, (*c*) 2 hours at room temperature plus 20 minutes on a rack over hot water (179°F, 82°C), (*d*) 24 hours in the refrigerator (50°F, 10°C), (*e*) 50 minutes submerged in cold (tap) water (79°F, 26°C), (*f*) 35 minutes submerged in hot water (113°F, 45°C).

Baking Covered and Uncovered. When one thawing procedure proved preferable to the other methods, paired samples defrosted by this method were used to explore the advisability of cooking fillets covered or uncovered. They were cooked "uncovered" (aluminum foil left open), or "covered" (aluminum foil wrapped tightly), or covered for part time and uncovered for the remainder, at 300 and 500°F.

RESULTS AND DISCUSSION

As has been mentioned, there were difficulties in using frozen samples, which resulted in a decision to thaw samples before baking. The data from testing the six different defrosting methods for this series are presented in Table I.

In that Table showing the comparisons, the various methods of treatment are arranged in order of the amount of thawing drip produced. It is obvious that a steady rise in the amount of thawing drip is accompanied by a corresponding rise in the length of time and the temperature used in the different defrosting methods. This consistent increase does not appear, however, in any of the other columns. Since the lowest amount of thawing drip results from a 24-hour defrosting in the refrigerator, with the fish at a temperature of 32 to 40°F (0 to 4.5°C), it may be assumed that this loss is due almost entirely to the disruption of muscle cells by the freezing process, thus allowing moisture and soluble products to escape. Fish are cold-blooded vertebrates and their enzymes are presumably capable of post-mortem activity at a lower temperature than those in the flesh of warm-blooded animals. Therefore, any increase of thawing drip above 3.1%

[3]Obtainable from Haugh–Gordon Ltd., Toronto.

TABLE I. Effect of thawing by six different methods on the thawing drip, oven losses, and moisture content of baked codfish fillets, using frozen fillets as a control.

Treatment	Oven Temperature	Losses			Organoleptic score	Moisture content of cooked fillet
		Thawing drip	Oven loss	Total		
	°F	%	%	%	%	%
Cooked frozen (control)	300	0	25.6	25.6	71.4	26.8
	500	0	23.0	23.0	68.2	25.5
(*a*) 24 hours in refrigerator	300	3.2	29.7	32.9	71.1	27.8
	500	3.1	28.1	31.2	71.6	26.5
(*b*) 4 hours at room temperature	300	4.6	28.1	32.7	71.6	28.5
	500	5.6	27.8	33.4	74.4	28.0
(*c*) Cold water for 50 minutes	300	6.6	27.3	33.9	80.0	29.4
	500	6.7	27.1	33.8	80.0	28.0
(*d*) 2 hours at room temperature plus 20 minutes over hot water	300	6.6	29.3	35.9	66.1	30.3
	500	6.5	27.1	33.6	68.1	30.1
(*e*) Hot water for 35 minutes	300	9.5	27.8	37.3	71.6	28.2
	500	9.0	26.7	35.7	73.8	27.6
(*f*) Overnight at room temperature	300	11.2	26.0	37.2	58.8	29.2
	500	13.3	25.1	38.4	57.2	28.9

may reasonably be supposed to be due to an increase in temperature and time during which enzymes, delayed by the low temperature, become activated. Their action causes breakdown of the tissues and these degradation products appear in the increased amount of thawing drip. This reasoning also explains why certain samples, judged too moist by the taste panel, did not show a corresponding increase in moisture analysis of the cooked product. The moistness could be due, not to additional moisture present, but to syneresis of the fish tissue which caused an actual breakdown in texture, and produced to the taste panel the sensation of moistness.

It is apparent also from Table I that the higher the temperature of thawing, the greater the amount of drip released. But this phenomenon seems to depend on two factors: temperature and time. With these two factors working together, it is conceivable that enzymes are given time to act on the fish and an opportunity to form some of the soluble products which escape in the drip. This reasoning is supported by the fact that when the thawing drip is heated, coagulation results, in a manner similar to the reaction of egg white to heat. A high extraction of thawing drip does not, however, safeguard additional loss during baking.

The cooking losses, as presented in Table I, are given as (i) thawing drip, (ii) oven loss including both oven drip and evaporation, and (iii) total. All values are expressed as percentage of frozen weight, being equivalent to the

usual terminology "A.P."—as purchased. For purpose of experimental study and evaluation, however, all values were expressed as percentages of both frozen and thawed weight because of the fact that the thawing drip is partly dependent on the amount of surplus water that happens to freeze with each fillet. If this is unusually high, the amount of flesh in a 1-pound fillet is considerably reduced and the cooking loss assumes economic importance. Obviously, in each case, the percentage of thawed weight is greater than the percentage of frozen weight, because the thawed weight is less than the frozen weight.

It is evident from Table I that frozen samples which were thawed in cold water for 50 minutes were rated highest by the taste panel. Lowest organoleptic scores were given to samples thawed overnight at room temperature (*f*). Hot-water immersion for 35 minutes (*e*), and room-temperature defrosting for 4 hours (*b*) produced the next lowest scores. There is a definite relation, apparently, between the quality of the cooked product and the temperature at which the fish thawed. The second most important factor is the length of time taken for this process. Thus the time–temperature relationship found in connection with the production of thawing drip is supported also by organoleptic ratings. The taste panel seemed particularly able to measure differences in both colour and flavour, which suggests that these are most affected by the thawing method chosen, especially if a high temperature is involved. Cooking as soon as possible after thawing reduced the time–temperature factor to a minimum.

Cold-water thawing, in spite of its high organoleptic score, produced values for thawing drip, oven losses, and moisture percentage in the cooked fillets which were midway between the highest and lowest figures resulting from the different methods. The overall values for this defrosting method, however, seemed optimum of all six methods tested. Consequently this thawing procedure was adopted for subsequent tests with thawed fillets and with fillets cooked covered and uncovered. This led to the accumulation of more data for cold-water thawing than the other methods, and when these were averaged, the values supported the choice of this defrosting method and even enhanced the superiority of this method of thawing.

There was no clear-cut difference in the moisture content of the cooked fillets (Table I) as determined on the various samples, using the A.O.A.C. (1955) method. This lack of consistency has also been reported by Charley and co-workers (1952, 1958) who determined moisture content by the press-fluid method. Variable results in baking losses and moisture retention of the cooked fish may be partly a result of biological differences in the fish itself. Charley and co-workers referred to this biological difference, not only between fish, but between different areas of the same fish, and previous work in this Department corroborated these differences. The age of the fish when caught, and the length of time it was held frozen in storage, are variables which could not be checked, yet which undoubtedly have a direct bearing on experimental results.

Charley's (1952) conclusion that "there is no significant difference in any of the five palatability characteristics associated with oven temperature" is

supported by our results with frozen codfish fillets. When the data from cooking the fillets at 300°F are compared with those from cooking at 500°F, the differences are not consistent. In fact it is evident that at either temperature a good product can result, providing certain methods of thawing are used.

TABLE II. Effect of cooking codfish fillets covered and uncovered as measured by organoleptic tests, cooking losses, and moisture content of the cooked product.

Treatment time			Losses				
Covered	Uncovered	Oven temperature	Thawing drip as % frozen weight	Oven loss as % frozen weight	Total	Organoleptic score	Moisture content of cooked fish as % of cooked weight
minutes	*minutes*	°F			%	%	
...	60	300	4.8	26.6	31.4	77.7	30.7
...	20	500	5.8	26.3	32.1	75.1	30.0
60	...	300	5.4	15.9	21.3	68.3	27.2
20	...	500	7.0	15.2	22.1	62.7	25.3
50	10	300	4.7	21.4	26.1	67.7	28.5
15	5	500	4.0	21.6	26.1	63.8	26.1
45	15	300	5.0	22.1	27.2	71.1	25.8
10	10	500	5.5	21.3	26.8	73.3	26.0

It may be noted from Table II that, despite inconsistency in moisture content of the cooked fillets, shown in Table I, there is a consistency in the moisture content of fillets cooked covered and uncovered. Invariably the fillet which was cooked uncovered had the higher moisture content. It is assumed that this result is due to the formation of a very thin, relatively impervious layer of dried-out flesh covering the exposed surfaces of the samples, which held in the moisture. According to this reasoning it was to be expected that fillets cooked uncovered for 60 minutes at 300°F would retain the most moisture, and the results supported this explanation. Samples cooked uncovered at the higher temperature (500°F) for 20 minutes retained nearly as much moisture as those cooked at the lower temperature.

As the investigation proceeded, it became obvious that there frequently is a great difference in the quality of frozen codfish "fillets" as offered on the consumer market. In addition to occasional unacceptability due to prolonged storage or delayed freezing or age of the fish, over 16% of the fish used in these experiments labelled "fillets of cod" was in small pieces. This resulted in a sacrifice of moistness, flavour, tenderness and palatability because of greater surface area exposed in baking.

Finally, since cold-water defrosting proved acceptable in these experiments, and since pliofilm bags were convenient to use, it is suggested that marketing frozen fillets in sealed pliofilm bags might make fish increasingly acceptable as a high-quality food, not only by offering an opportunity for the consumer to examine the contents, but also by facilitating thawing procedure.

SUMMARY AND CONCLUSIONS

Using 1-pound commercial frozen codfish fillets, maintained in a freezer at 5 to 10°F, two similar samples were prepared from each fillet. These were defrosted in six ways before cooking at 300°F and 500°F respectively in thermostatically controlled ovens. Samples of cooked fish were compared organoleptically. Moisture content of the cooked product, drip losses and total cooking losses were calculated as percentages of both frozen and thawed weight. In some initial experiments in which fillets were cooked directly from the frozen state to assess degree of "doneness", the taste panel scores were not as favourable as when fillets were thawed before cooking. The following conclusions are drawn from the results of experiments on pre-thawed fillets only.

1. Of six different methods of thawing studied, defrosting by submersion in tap water for 50 minutes resulted consistently in a more palatable cooked product. Thawing overnight at room temperature produced the least acceptable cooked product. Low rating of fish defrosted by other methods leads to the conclusion that the method of thawing is one of the most important steps in the preparation of an attractive fish product.

2. There was no appreciable difference in acceptability of fish cooked at 300°F or 500°F, and neither moisture retention nor cooking loss varied significantly.

3. Samples cooked uncovered at 300°F and 500°F were rated more attractive, more palatable, and better-flavoured than those cooked covered.

4. Suggestions are made for the improvement of wholesale and retail packaging.

REFERENCES

ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS (A.O.A.C.). 1955. Official and tentative methods of analysis. Eighth edition, Washington, D.C., 1084 pp.

CANADA DEPARTMENT OF NATIONAL HEALTH AND WELFARE, NUTRITION DIVISION. 1951. Table of food values recommended for use in Canada.

CHARLEY, HELEN. 1952. Effects of internal temperature and of oven temperature on the cooking losses and the palatability of baked salmon steaks. *Food Research*, **17**(2): 136–143.

CHARLEY, HELEN, AND GOERTZ, GRAYCE E. 1958. The effects of oven temperature on certain characteristics of baked salmon. *Food Research*, **23**(1): 17–24.

ELGIN, LOIS C., KATHRYN L. OSTERHAUG AND THELMA S. ROSE. 1957. How to cook frozen fish without prethawing. Part II—The effect of oven temperature on cooking time for frozen halibut steaks. *Comm. Fish. Rev.*, **19**(7): 1–7.

HILDITCH, T. P. 1940. The chemical constitution of natural fats. John Wiley and Sons, 438 pp.

MCLESTER–DARBY. 1953. Nutrition and diet in health and disease. Sixth edition: W. B. Saunders Co., 710 pp.

OSTERHAUG, KATHRYN L., AND MARIAN M. MACFARLANE. 1955. How to cook frozen fish without prethawing. Part I—Determination of optimum internal temperature for baked frozen halibut steaks. *Comm. Fish. Rev.*, **17**(11): 12–14.

Incidence and Distribution of Infestation by *Sphyrion lumpi* (Krøyer) on the Redfish, *Sebastes marinus* (L.), of the Western North Atlantic[1]

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ABSTRACT

Investigations of infestation of redfish by female *Sphyrion lumpi*, in the Newfoundland area, showed that in the Labrador area *Sphyrion* were generally distributed all over the body but with the greatest infestation in the cloacal region. In the eastern Grand Bank area there was a strongly ventral distribution of the parasite on the trunk with over 40% of the parasites in the cloaca. This is contrasted with previously published data from the Gulf of Maine where most of the *Sphyrion* were situated antero-dorsally, near the base of the spiny first dorsal fin.

The major centre of infestation, in the Newfoundland area, of redfish by *Sphyrion* was off southern Labrador east of Hamilton Inlet Bank with as high as 8% of the redfish infested. Centres of less infestation were found on the southern part of the eastern slope of the Grand Bank and in the southeastern part of the Gulf of St. Lawrence. *Sphyrion* were very scarce on the southwestern Grand Bank, the western part of the south coast of Newfoundland and in the northern part of the Gulf of St. Lawrence. *Sphyrion* were not noted on redfish from the NE Grand Bank, Flemish Cap and from the Nova Scotian Shelf. A study of residual remains, in redfish fillets, of the cephalothorax from individuals of previous *Sphyrion* generations showed the same centres of abundance but with some spreading of the previously infested fish in 2 of 3 areas in the direction of the deep-water current, thus indicating the possibility of very slow migration of some individual redfish with the current.

It is believed that almost all the redfish discussed in this paper are of the *mentella* type.

INTRODUCTION

The copepod parasite, *Sphyrion lumpi*, a member of the family Sphyriidae was first described by Krøyer (1845, 1863) and more recently by Wilson (1919).

The species *Sphyrion lumpi* (Krøyer) is sexually dimorphic in the adult stages. The males have been described by Wilson (1919). They are about 2 mm long as adults and attached to the females but the males of the Sphyriidae retain the ability to crawl. The female, on the other hand passes through the copepodid stage and adapts its structure to a fixed attachment of the cephalothorax in the flesh of a fish, usually in the western North Atlantic a redfish, *Sebastes marinus* (L.). This paper deals only with the female *Sphyrion lumpi*. The greatest lengths (exclusive of ovisacs) of the *Sphyrion lumpi* observed lay between 9 and 80 mm with very few smaller than 20 mm in length.

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The material and information presented here have been gathered mainly during the exploratory work on redfish carried out by the *Investigator II* and also, to some degree, on board local trawlers. We have made additional examinations of redfish on shore, in Job Brothers fresh fish plant at St. John's and particularly at the Biological Station, to check the adequacy of the sea examinations. The period of observation has included the years from 1947–1953 but before 1949 observations were more casual than during the period 1949–1953 which is dealt with in this paper.

When these observations began it was known from the work of Herrington, Bearse and Firth (1939) and of Nigrelli and Firth (1939) that there was a centre of relatively heavy *Sphyrion* infestation in the Gulf of Maine. Our observations in recent years have shown a similar area of high infestation off the Labrador coast, a minor focus of infestation on the eastern slope of the Grand Bank and probably at the southern slope of the Cabot Strait entrance to the Gulf of St. Lawrence, and very low infestation or no infestation in many other areas.

Preliminary summaries of the incidence and distribution of *Sphyrion lumpi* on redfish in the Newfoundland area have been given by the senior author in the report of the Biological Station, St. John's, Nfld. (1951) and in two other publications (Templeman, 1953, 1955).

In our work *Sebastes marinus marinus* (L). and *Sebastes marinus mentella* Travin have been distinguished only since 1956. Thus in a strictly correct sense it is possible to refer to the redfish of this paper for the period 1949–1953 only as *Sebastes marinus* (L.). It is, however, certain from our knowledge of the relative numbers of redfish of the *mentella* and *marinus* forms in the Newfoundland-Nova Scotian areas from which the redfish samples were taken that almost all the redfish included in this paper are of the *mentella* type (Templeman, 1959).

The Parasite

Although we have nothing new to add to descriptions of anatomical details of *Sphyrion lumpi* given by previous authors a brief description is given here as an introduction to the data to be presented.

Two views of a mature *Sphyrion lumpi* with ovisacs are shown in Fig. 1. The female possesses a hammer-shaped cephalothorax (which for brevity we shall usually refer to as the head) with swollen terminal lobes, joined to a heart-shaped trunk by a long slender neck. Situated dorsally at the posterior end of the trunk is a pair of short blunt protuberances, the caudal rami and lying in close association with them is a pair of multibranched arborescent organs. When the female parasite is mature long ovisacs develop from the pits outside the caudal rami.

After the larvae which develop in the ovisacs are hatched out and the ovisacs are eventually lost the trunk shrivels, its contents degenerate and the animal dies. The trunk and the external portion of the neck soon disappear but the cephalothorax (after this called the head) is often or usually left embedded in the flesh of the host and often surrounded by a cyst-like tissue. In areas where *Sphyrion* infestation is great it is necessary to remove these old dark-brown "heads" and the cysts around them from the fillets before these are marketed.

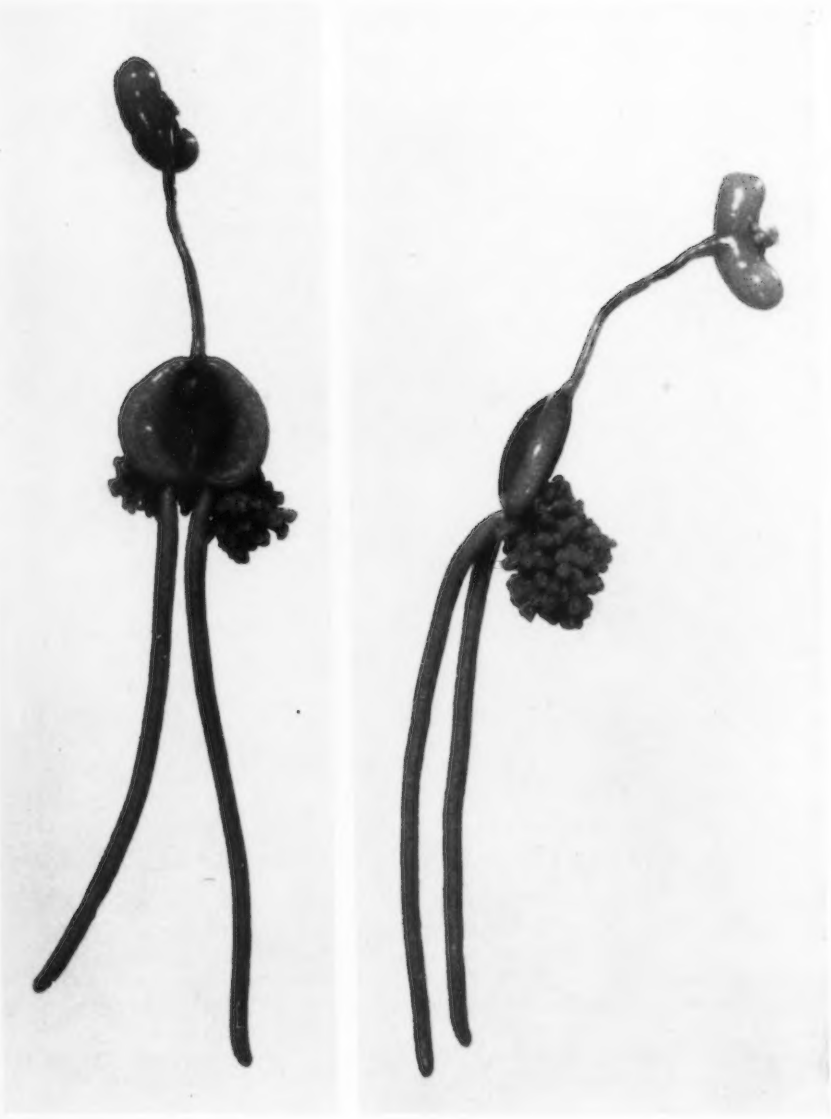

FIG. 1. Dorsal and lateral views of mature *Sphyrion lumpi* with ovisacs (natural size).

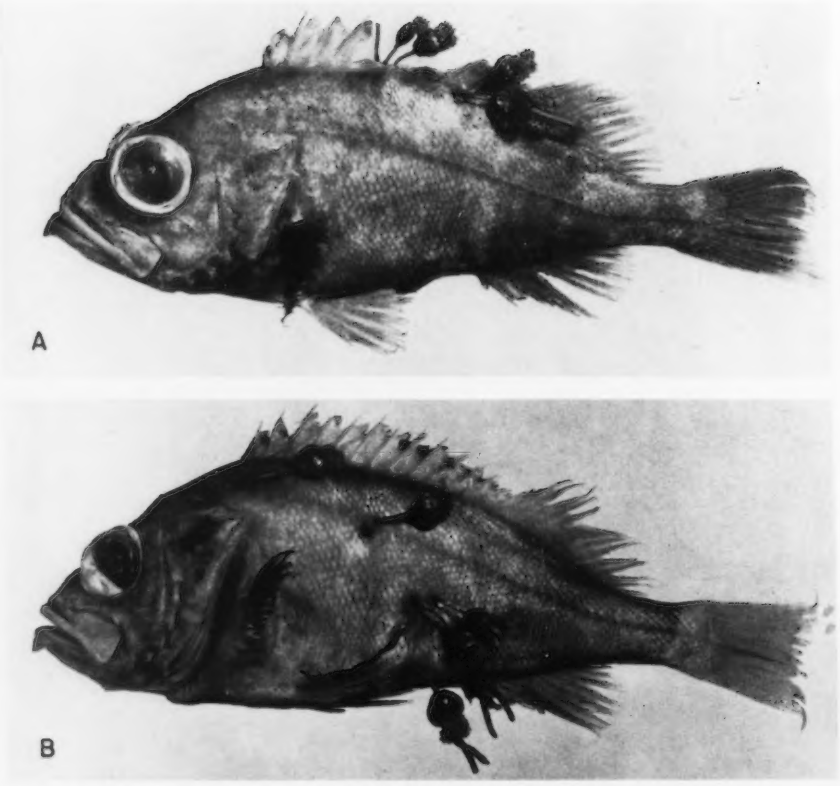

FIG. 2. *Sphyrion lumpi* (0.33X) on *mentella*-type redfish from the eastern slope of Hamilton Inlet Bank, Labrador. (In "A" part of the dorsal fin has been cut away to reveal the two *Sphyrion* and the neck stalk of a third *Sphyrion* emerging on the right side close to the dorsal fin. In "B" additionally to the 5 *Sphyrion* there is a small scar, just below the lateral line, close to and in front of the centre of emergence of the second *Sphyrion* from the anterior end, showing the recent position of emergence of a sixth *Sphyrion*.)

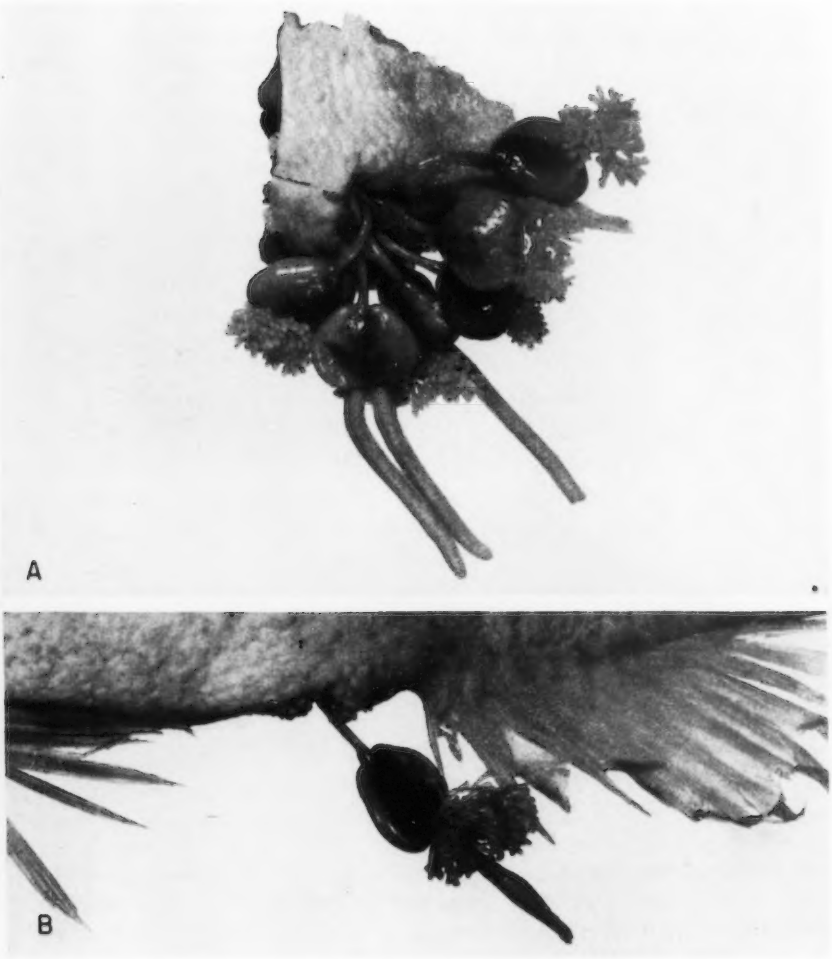

FIG. 3. *Sphyrion lumpi* (natural size) attached to the cloacal region of redfish from the eastern slope of Hamilton Inlet Bank, Labrador. (A—6 *Sphyrion*, B—1 *Sphyrion*.)

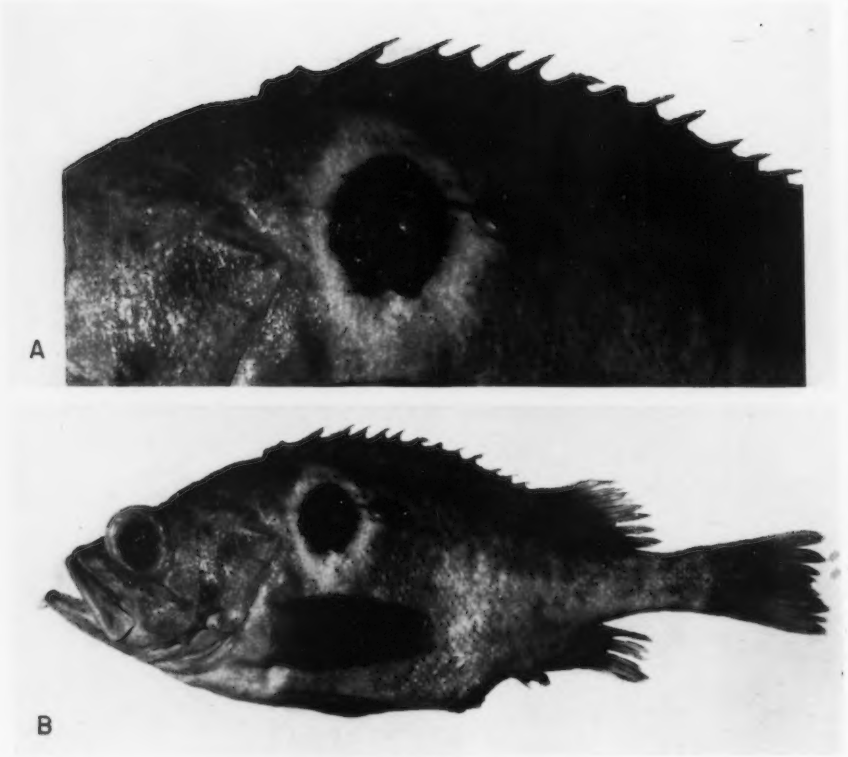

FIG. 4. *Sphyrion lumpi* attached through a tumour on the body of a female *mentella*-type redfish, 45 cm in length, from the NE Grand Bank, 250 fathoms, 457 m. (A, 0.6X; B, 0.27X).

The typical appearance of *Sphyrion* on the redfish body is shown in Fig. 2. Fig. 3 depicts *Sphyrion* attached in the cloaca—a very usual location on redfish of the Newfoundland area. In Fig. 4 is seen a *Sphyrion* in the midst of a tumourous area where the skin has been destroyed. It is not likely that the *Sphyrion* has caused the tumour, but rather the *Sphyrion* has probably settled on a soft and easily penetrable area.

During the investigation it was noted that there is a great tendency for *Sphyrion* to settle in areas of easy penetration. Thus in an area with the skin abraded due to the presence of a *Sphyrion* there may occasionally be several *Sphyrion* present, often in different stages of maturity and of different ages. The abundant settling, to be described later, in the cloacal area is a similar occurrence.

Sphyrion Records and *Sphyrion* Hosts

Krøyer's (1845, 1863) original specimen of *Sphyrion lumpi* was attached to a lumpfish, *Cyclopterus lumpus* L., from Iceland. Krøyer (1863) had 4 young *Sphyrion lumpi* in addition to the above specimen but did not report the location of their capture nor their hosts.

Steenstrup (1869) and later Hansen (1923) report 2 specimens of *S. lumpi* from northern West Greenland, one from Umanak (Lat. 70°42′N) in 1865 and one from Ikerasak (Lat. 70°30′N) in 1864. The host is not mentioned.

Basset-Smith (1899) reports doubtfully a specimen in the British Museum taken off Dungeness, Scotland. Leigh-Sharpe (1928) reports 5 specimens from Dungeness which were the same specimens doubtfully called *Sphyrion lumpi* by Bassett-Smith but attributed by Leigh-Sharpe to *Sphyrion kingi* Cunningham. The host is not mentioned by either of these authors. Wilson (1919) says that Cunningham's (1871) description of *Sphyrion kingi* is not sufficiently detailed to establish this species. Leigh-Sharpe's (1928, p. 183) comparison of *S. lumpi* and *S. kingi*, however, and his figure of *S. kingi* leave little doubt that the Dungeness specimens were not *S. lumpi*.

Bassett-Smith also reports *Sphyrion lumpi* from *Cyclopterus lumpus* from Denmark. This is followed by some subsequent authors, Scott (1901), Wilson (1932), Nigrelli and Firth (1939). Some and probably all of these references actually refer not to a specimen from Denmark, but to specimens of *S. lumpi* from Iceland or Greenland in Danish museums.

Scott (1901) reports a specimen of *S. lumpi* on *Cyclopterus lumpus* captured in the Bay of Nigg near Aberdeen, April 1900, and Scott (1905) another specimen of *S. lumpi* obtained from a striped wolffish, *Anarhichas lupus* caught at 200 fathoms (365 m) (in the North Sea according to T. and A. Scott, 1913).

Hansen (1923) records 3 specimens of *Sphyrion lumpi* from a redfish, *Sebastes marinus*, taken by the *Michael Sars* in 275–300 fathoms (500–550 m) in the southern part of the Norwegian Sea in Lat. 62°30′N, Long. 1°56′E. These 3 specimens of *Sphyrion*, one very large, one of medium size and one small, were attached near the anus. According to the depth the host is likely to be *Sebastes marinus mentella* rather than *Sebastes marinus marinus*.

Stephenson (1940) gives 4 records of *Sphyrion lumpi* from Iceland and says that all Icelandic specimens were probably from *Cyclopterus lumpus*.

Å. Vedel Tåning (private communication, 1952) stated that he had never seen *Sphyrion lumpi* on Icelandic redfish. Paul Hansen (private communication, 1954) says that he has examined large numbers of redfish (and other fishes) in Greenland but has not seen *Sphyrion lumpi* in this area.

Meyer (1951) records a redfish from the Hamburg fish market bearing 3 *Sphyrion lumpi*. Evidently this occurrence was rare enough to be worthy of note.

Lüling (1951) says that he has noted female *Sphyrion* on redfish *Sebastes marinus* and up to 3 specimens on a single fish. He mentions as areas where *Sphyrion* are most likely to be attached: the cloaca and the musculature near the cloaca, near the caudal and anal fins, the operculum and the base of the pectoral fins. He shows a figure of 2 *Sphyrion* embedded in the cloaca of a redfish (48 cm long) from off the Norwegian coast in 350–370 metres.

Wilson (1919) has recorded *Sphyrion lumpi* from a salted hake, from several specimens of *Nematonurus goodei* (now *Nematonurus armatus* (Hector)) taken off the New Jersey coast, from a specimen of *Haloporphyrus viola* (the blue hake, now *Antimora rostrata* Günther) and from a *Sebastes marinus* taken off Cape Cod.

We have obtained one specimen of *Sphyrion lumpi* from a striped wolffish (*Anarhichas lupus*) of the Newfoundland area and also a specimen of this parasite with a head width of 1.0 cm from a male broad-headed wolffish (*Anarhichas denticulatus* Krøyer), 55 cm long, taken Aug. 7, 1958, east of Hamilton Inlet Bank in Lat. 54°47′N, Long. 53°40′W, at 250 fathoms (460 m). The parasite was situated about $\frac{2}{3}$ the length of the body posteriorly from the head and about half way up the right side. Another specimen of *Sphyrion* on the broad-headed wolffish of the northern Newfoundland-southern Labrador area has been noted by one of the technicians of the St. John's Station but was not returned to the Station to be checked by the authors. On a recent cruise of the *A. T. Cameron* in August–September, 1959, it was noted that *Sphyrion lumpi* was not uncommon on the rough-headed grenadier, *Macrourus berglax* Lacépède, off Baffin Island and northern Labrador.

In the North American area *Sphyrion lumpi* is a common parasite of the redfish, but it is more unusual to see the parasite on other fishes from this area.

Apart from Lüling's (1951) observations which indicate that *Sphyrion* is not rare on redfish obtained by German trawlers, there is little indication that *Sphyrion* are as plentiful in the Icelandic and European areas as in the North American area. Around Iceland it is apparently more likely to be seen on lumpfish than on redfish, and in the northeastern European area lumpfish, striped wolffish and redfish are hosts but as far as we know the parasite does not occur in great numbers in these areas.

However, until recently most of the redfish captured in the European area were *Sebastes marinus marinus*. The parasite, if it occurs more readily on the *mentella* than on the *marinus* form of redfish, may have been overlooked on the scarcer *mentella*. Presumably, to maintain a *Sphyrion* population there must be centres of abundance of the parasite somewhere in the European area.

Most of the present European literature regarding the degree of infestation of European and Icelandic redfish by *Sphyrion* very likely concerns *Sebastes marinus marinus* which until recently was by far the chief redfish form fished in these areas. The *Sphyrion* infestations in the Newfoundland area, and presumably in the North American area generally, are principally of *Sebastes marinus mentella*, which is the common form of redfish in the area. With the increasing fishery in the European area in recent years for the *mentella* form of redfish, it is possible that more instances of *Sphyrion* occurrence on redfish will be noted.

In the Newfoundland area we have noted only one small immature *Sphyrion* on *Sebastes marinus marinus* and this was attached in the cloacal region of a 48 cm fish obtained in late August, 1958, from the Hawke Channel region off Hawke Harbour in southern Labrador. The *marinus* form appears to have a thicker skin and epidermis and certainly the scales are much more firmly fixed in comparison with those of *mentella*, which are readily lost. Thus it may be more difficult for a young *Sphyrion* to penetrate the skin of the *marinus* than of the *mentella* form. In the Newfoundland area, also, the centre of abundance of *Sphyrion* is deeper than the level of abundant populations of *marinus*-type redfish while being everywhere well within the range of the *mentella* form.

Seasonal Rhythm and Abundance

Nigrelli and Firth (1939) found no definite correlation between the time of year and the numbers of *Sphyrion* parasites visible externally. They, however, found young parasites present underneath the skin during the late summer and early fall and assume that these grow large enough to become externally visible by spring, reaching maturity by summer. Herrington *et al.* (1939) give tables of Gulf of Maine redfish infested by externally visible *Sphyrion lumpi* in February–May, June–September and October–January. These tables indicate no great or consistent differences between the degree of infestation in these groups of months, but show the possibility of slightly greater infestation in the February–May period.

From our own material, since the only major centre of high infestation, Labrador, was visited only once a year and that usually in September, we have made no attempt to present the percentage of redfish infested per month. The lack of great differences between months makes it more reasonable to lump together the data for all months, and this has been done in the various figures and tables considered in the remainder of the paper.

DISTRIBUTION OF *SPHYRION LUMPI* ON REDFISH

The pattern of the centres of emergence of live *Sphyrion lumpi* from the body of the redfish is shown in Fig. 5B, 5C and 6 for the only two Newfoundland areas for which there are many records of *Sphyrion*. No old and dead neck stalks, scars and sores produced by *Sphyrion lumpi* or lumps caused by embedded old heads are included. For comparison we have included in Fig. 5A and 7A adapted

diagrams (parasites only, not sores which were included in the original paper) of the distribution of *Sphyrion* positions of attachment on redfish in the Gulf of Maine given in a little known paper by Herrington, Bearse and Firth (1939); and in 7B, a figure after Perlmutter (1951).

The paper of Herrington *et al.* is based on *Sphyrion* data gathered from redfish landings at the Boston Fish Pier between January, 1938, and February, 1939. The *Sphyrion* parasites were all from redfish of the Gulf of Maine. Perlmutter's data (Fig. 7B) were obtained from November, 1942, to October, 1943. Again the *Sphyrion* probably came from shore landings and certainly from the Gulf of Maine.

Our data were collected almost entirely at sea during the measurements of random samples of fresh redfish from otter-trawl catches mainly by research vessels and to a small degree from commercial otter trawlers. Compared with the Gulf of Maine data, far fewer *Sphyrion* were situated dorsally above the lateral line, only 25% in Labrador and 12% on the East Grand Bank compared with 75% (Herrington *et al.*) and 92% (Perlmutter). An even greater contrast existed between the relative numbers of *Sphyrion* between the bases of the dorsal spines and the lateral line, 13% Labrador and 5% East Grand Bank compared with 64% (Herrington *et al.*) and 90% (Perlmutter). A still greater difference was found in the percentages of *Sphyrion* in the two anterior sectors below the spiny first dorsal fin (Sectors A and B of each part of Fig. 6 and 7) 1% and 3%, Labrador; 0% and 1%, East Grand Bank; as against 13% and 22% observed by Herrington *et al.*, and 36% and 33% by Perlmutter.

Again there is a great contrast between the percentages of *Sphyrion* in the cloaca and those in the neighbouring posterior region: in Labrador, 25% and 11% respectively; East Grand Bank, 42% and 9%; Gulf of Maine, 3% and 1% (Herrington *et al.*); and 3% and 0.2% (Perlmutter).

The central area of the redfish, below the lateral line (Sectors J, K, L, M) contains 17% of the *Sphyrion* in Labrador, 8% in East Grand Bank, and in the Gulf of Maine, 0% (Herrington *et al.*) and possibly 1% (Perlmutter).

Herrington *et al.* state that the greatest concentration of *Sphyrion* in the heavily infected dorsal area was at the base of the spiny first dorsal fin (Fig. 5A). Perlmutter (1951) says that most of the *Sphyrion* in the dorsal spine region were closer to the base of the dorsal spines than to the lateral line. In the Labrador area, also (Fig. 5B), although there is a smaller percentage of the parasites in the dorsal region than in redfish from the Gulf of Maine most of those above the lateral line in the region of the spiny first dorsal are closer to the first dorsal than to the lateral line. In the East Grand Bank area (Fig. 5C) the parasites are situated more ventrally and only one parasite out of 133 was near the base of the spiny first dorsal.

The main differences, therefore, seem to be an antero-dorsal distribution of *Sphyrion* mainly near the base of the spiny first dorsal fin in the Gulf of Maine;

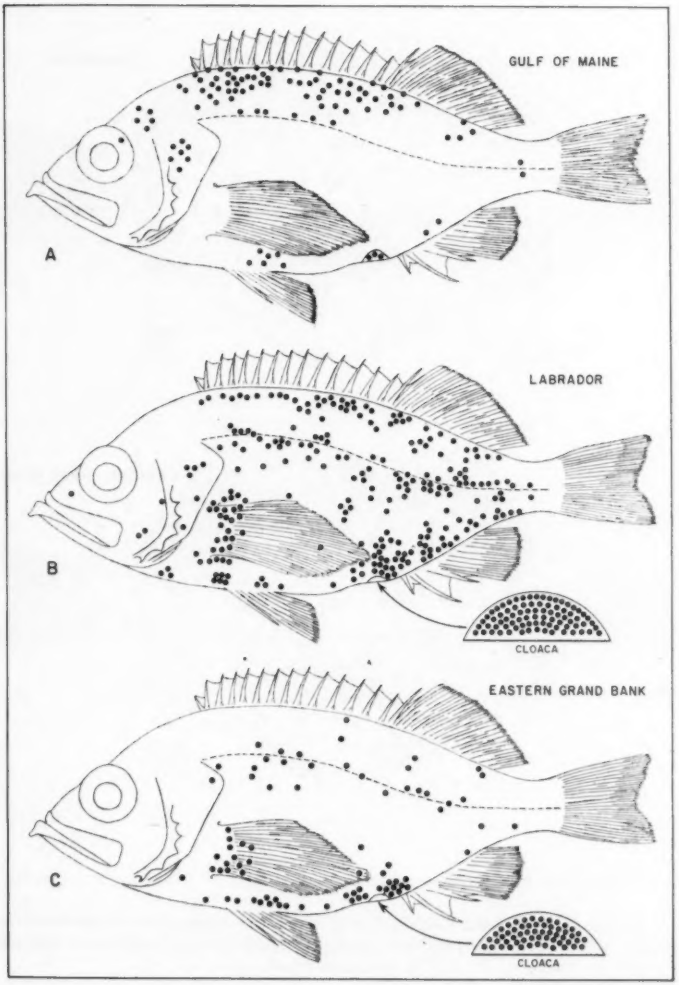

FIG. 5. Centres of emergence of *Sphyrion lumpi* on redfish: from A, the Gulf of Maine, after Herrington, Bearse and Firth, (1939); B, Labrador; C, eastern slope of the Grand Bank, 1949–1953.

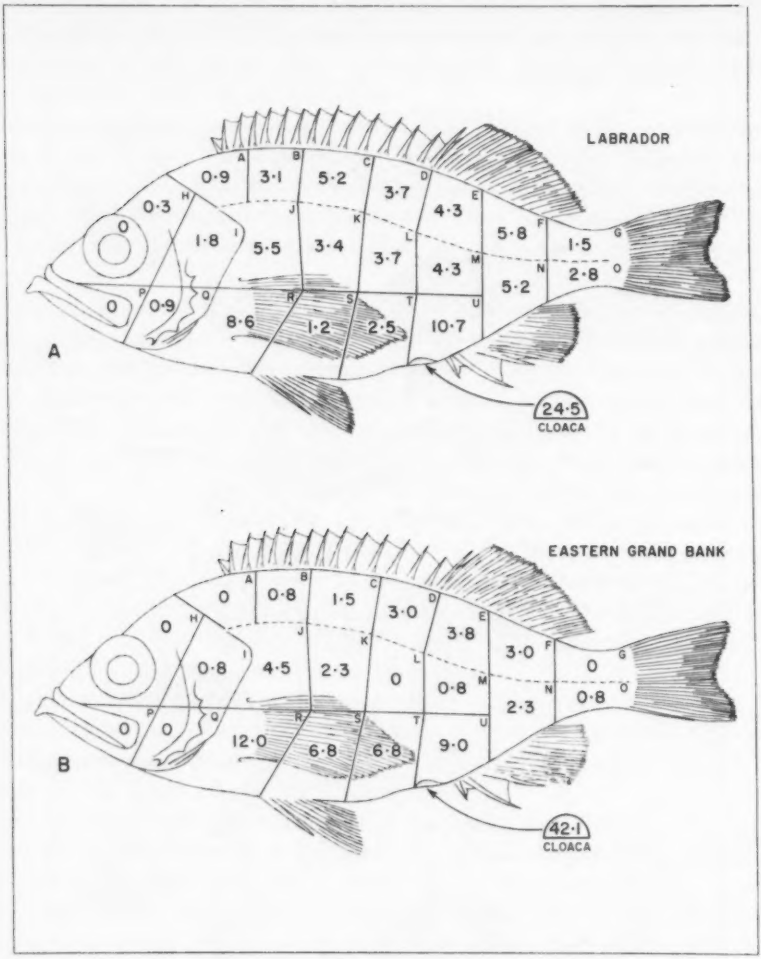

FIG. 6. Percentage sectional distribution of centres of emergence of *Sphyrion lumpi* on redfish. A, from Labrador; B, from the eastern slope of the Grand Bank, 1949–1953.

a fairly general distribution all over the body of the redfish in the Labrador area, but yet with a heavy distribution in the small soft cloacal region; and a strongly ventral distribution on the trunk in the eastern Grand Bank area with over 40% of the parasites in the small cloacal area.

The Gulf of Maine samples of Herrington *et al.*, and very likely those of Perlmutter also, were from redfish landed under ice. Our samples were mainly (86%)

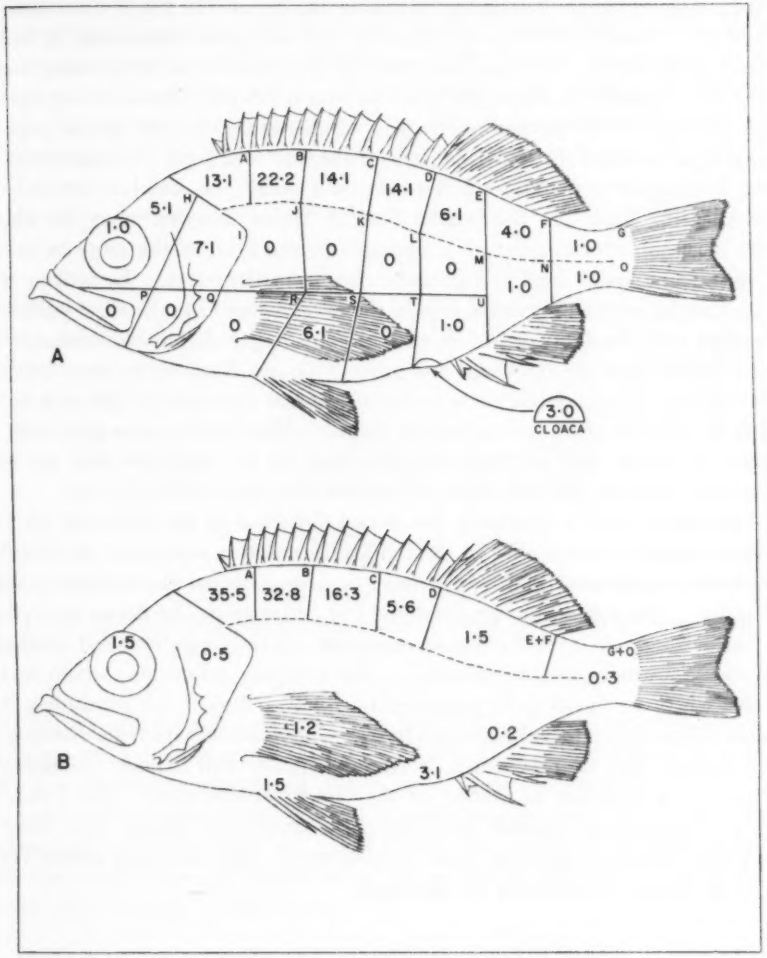

FIG. 7. Percentage sectional distribution of centres of emergence of *Sphyrion lumpi* on redfish from the Gulf of Maine. A, after Herrington, Bearse and Firth (1939); B, after Perlmutter (1951).

fresh samples whose *Sphyrion* parasites were observed while the redfish were being measured immediately after capture by the otter trawl. Samples of redfish were always measured and the sex recorded; although *Sphyrion* were always noted and although in areas of high infestation, such as Labrador, each measured fish was systematically turned over and examined for *Sphyrion*, it cannot be certain that in areas of scarce *Sphyrion* infestation every fish was so carefully examined

on both sides. In our measuring of redfish the sex of the fish is also recorded, and in the period covered by this paper the fish were sexed externally by looking at the cloacal region. (Redfish less than 25 cm, a few of the larger ones, and all specimens of redfish in which the sex was doubtful were afterwards cut open to check the sex.) This method of checking would assure that the cloacal area was observed and most of the *Sphyrion* parasites in that area seen. On the remainder of the body most of the larger *Sphyrion* would usually be seen but certainly not all of the tiny ones. In the landed Gulf of Maine samples, since the cloacal region does not offer as good an anchorage for the head of the parasite as does the more solid dorsal area, and parasites frozen in the ice may be broken off in the neck region or possibly in the case of the cloacal area have the head pulled out, it may be that the Gulf of Maine cloacal percentages should be comparatively a little higher and the Labrador and eastern Grand Bank areas comparatively a little lower. The differences, however, in general positions of *Sphyrion* on the redfish of the Gulf of Maine and in the Newfoundland areas are so great and the number of redfish and of *Sphyrion* examined are so adequate that we must tentatively conclude that the main differences discussed above are real.

Perlmutter (1951) attributes the dorsal situation of the *Sphyrion* on Gulf of Maine redfish to the ability of the redfish, as noted in aquarium specimens of other fishes, to roll over and scrape away parasites against the bottom or other solid object. The roll is only a partial one and *Sphyrion* on the dorsal part of the fish, especially in the anterior region, would be relatively undisturbed compared with those on other parts of the body. The scraping action also would be less effective wherever the body is protected by folds of flesh or by protruding fins. Possibly this is the correct explanation for the Gulf of Maine *Sphyrion* distribution on the redfish body but evidently it cannot equally well explain the different distribution of *Sphyrion* on redfish of the Newfoundland area. The Labrador and East Grand Bank redfish, however, are located more deeply than those of the Gulf of Maine and possibly on softer bottoms so that a scraping action would have little chance of removing the parasites.

OLD HEADS OF *SPHYRION* IN REDFISH FILLETS

In addition to observations on *Sphyrion* location on the fish some observations were made on the numbers of old heads of dead *Sphyrion* in the fillets. When the *Sphyrion* parasite spawns and dies, the old head of the parasite often remains embedded in the flesh, drying up to a very hard brown lump, sometimes with a cyst-like formation around it.

At the Station, on a glass-covered candling table with an electric light underneath, redfish fillets from various Newfoundland areas were examined for the

presence of these old heads. All heads of whole *Sphyrion* of the living generation had previously been removed from the fillets. During the examination the skinned fillets were sliced into thin sections so that the old *Sphyrion* heads could be seen. In this examination no account was taken of old heads in the cloacal or body cavity regions nor in parts of the fish not included in the fillet. The distribution of old *Sphyrion* heads in the fillets is shown in Fig. 8.

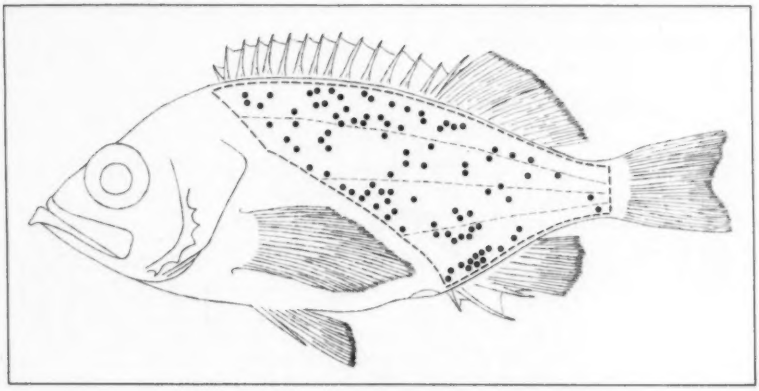

FIG. 8. Positions of old dead *Sphyrion* heads in fillets of redfish from the Newfoundland area, 1949–1953.

The numbers examined were too few and the area too vast for critical between-area comparisons of the sites of infection in the fillets, consequently data for all Newfoundland and neighbouring areas are included in Fig. 8. The general result is more related to the Labrador distribution (Fig. 5B) than to that of the Gulf of Maine (Fig. 5A). The sites of the old heads are well spread over the fillet with some concentration in the central dorsal region and in the part of the fillet posterior to the cloaca.

SPHYRION ABUNDANCE ON REDFISH IN VARIOUS PARTS OF THE NORTHWEST ATLANTIC

Figure 9 shows the locations where samples of redfish were collected for studies of the incidence of *Sphyrion lumpi*. The amount of external infestation by living *Sphyrion* is indicated in Fig. 10 and 11 and the numbers of dead and often encysted *Sphyrion* heads from previous generations of *Sphyrion* are shown in Fig. 12 and 13. Whereas the living *Sphyrion* are from the whole fish, the dead *Sphyrion* heads are from the fillets only.

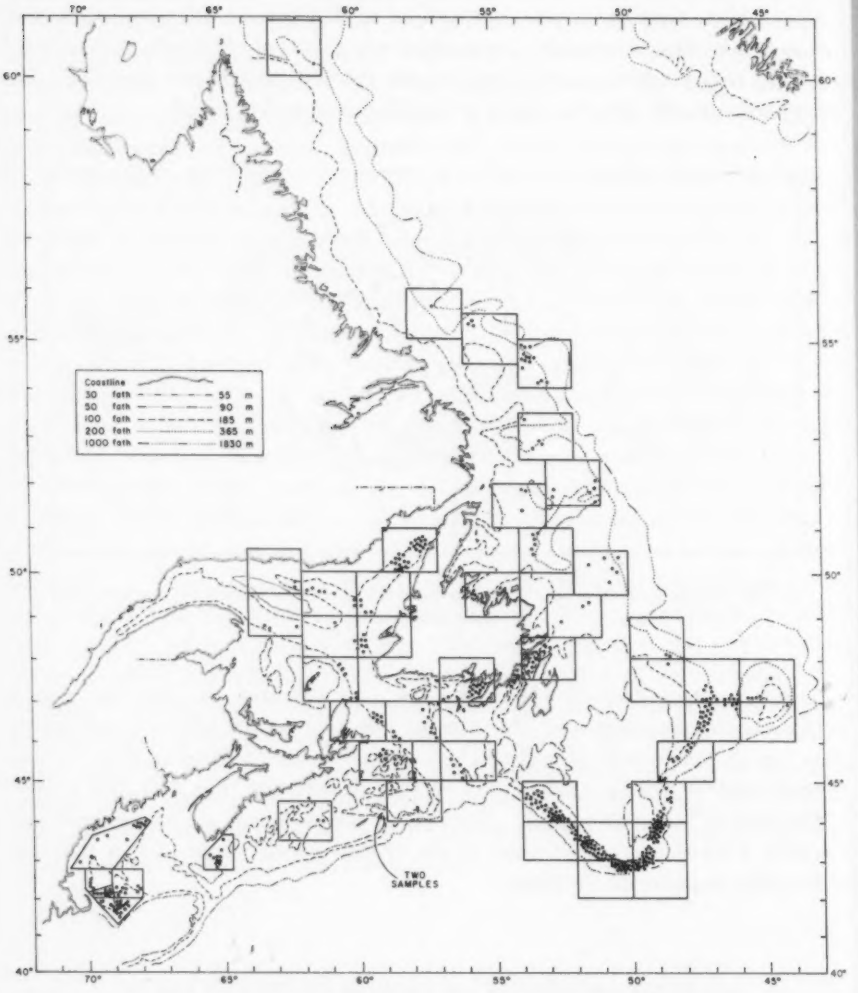

FIG. 9. Locations of samples of redfish examined for *Sphyrion lumpi* to obtain data for Fig. 10 and 11 and for the other tables and figures included in this paper. (Limited numbers of redfish from these samples were examined internally to obtain the data included in Fig. 12 and 13.)

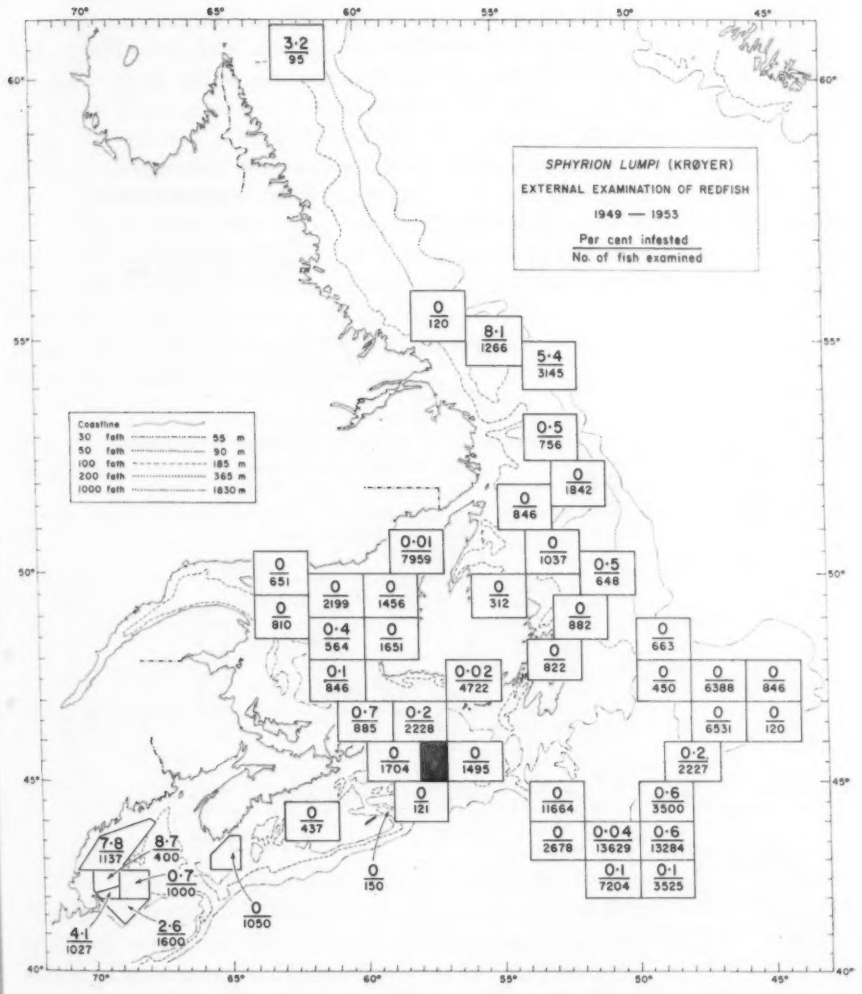

FIG. 10. Percentages of redfish in various parts of the Northwest Atlantic infested by externally visible entire *Sphyrion lumpi*. (All numbers in large rectangular areas of equal size are from our 1949–1953 records, the remainder, including all the Gulf of Maine samples, one on the SE part of the Nova Scotian Shelf and one from the Banquereau–Sable Island Bank Gully are after Herrington, Bearse and Firth, 1939.)

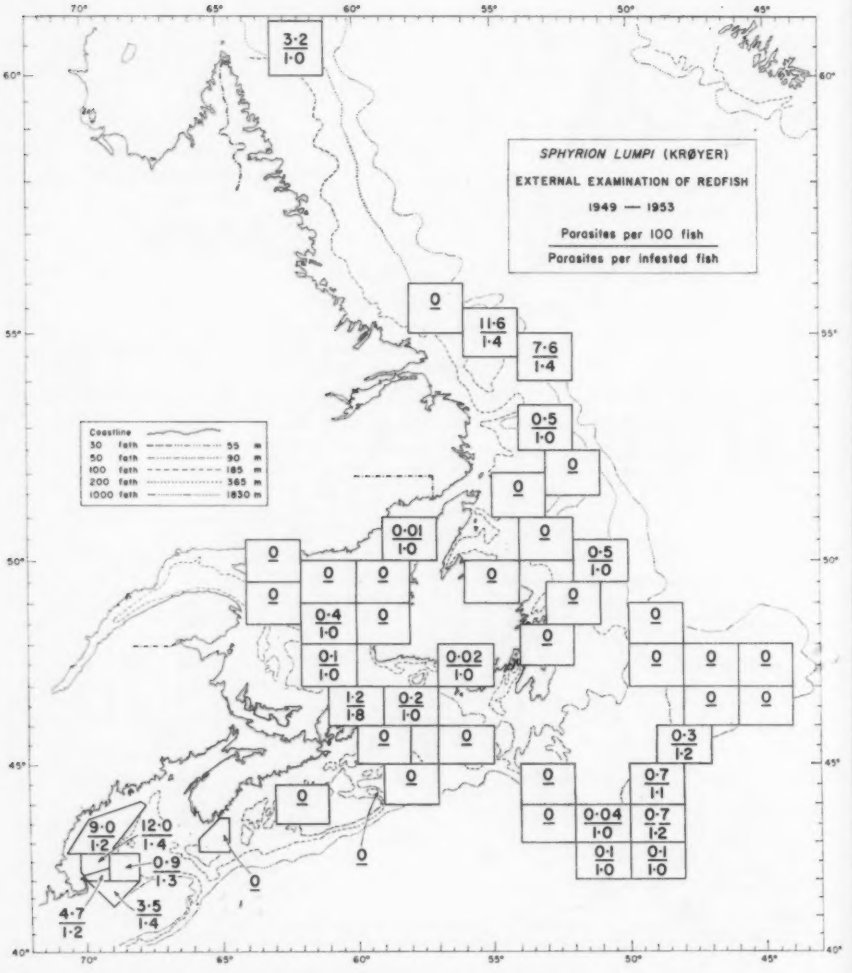

FIG. 11. Numbers of externally visible entire *Sphyrion lumpi* per 100 redfish in various parts of the Northwest Atlantic and the numbers of these parasites per infested fish. (Other remarks are similar to those in parentheses for Fig. 10. Numbers of fish in samples are identical with those in Fig. 10.)

LIVING *Sphyrion*—EXTERNAL

INFESTATION AND LOCALITY. The major centre of infestation (Fig. 10) is off Labrador east of Hamilton Inlet Bank. Because there was a moderately high rate of infestation, also, in the small sample of redfish examined from off the northern tip of Labrador, it is possible that other centres of high infestation by *Sphyrion* occur among the populations of redfish along the Labrador coast north of Hamilton Inlet Bank. There are other centres of infestation on the southern two-thirds of the eastern slope of the Grand Bank and in the south-eastern part of the Gulf of St. Lawrence.

Sphyrion were very scarce on the southwestern slope of the Grand Bank, the western part of the south coast of Newfoundland and the northern part of the Gulf of St. Lawrence. In the present survey *Sphyrion* were not noted on redfish from the northeastern Grand Bank and Flemish Cap and from the Nova Scotian Shelf. It is also indicated (Table I) that redfish of intermediate size are the most likely to be infested by *Sphyrion*.

TABLE I. Infestation of redfish by externally visible *Sphyrion lumpi*. (The numbers of redfish examined are shown in parentheses. Redfish lengths are total lengths, chin to mid-fork of caudal fin.

Redfish length range	Percentage of redfish parasitized by *Sphyrion*					
	Male		Female		Male and female	
	Labrador	Eastern Grand Bank	Labrador	Eastern Grand Bank	Labrador	Eastern Grand Bank
cm	%	%	%	%	%	%
20–24	3.5 (57)	0 (39)	6.3 (48)	0 (19)	4.8 (105)	0 (58)
25–29	6.9 (247)	0.11 (907)	3.8 (291)	0 (264)	5.2 (538)	0.1 (1,171)
30–34	8.2 (692)	0.06 (1,810)	6.4 (640)	0.4 (751)	7.4 (1,332)	0.2 (2,561)
35–39	5.9 (745)	0 (166)	11.0 (535)	1.6 (1,208)	8.0 (1,280)	1.5 (1,374)
40–44	0 (79)	0 (1)	3.4 (178)	0.9 (330)	2.3 (259)	0.9 (331)
45–54	...	...	...	0 (15)	...	0 (15)
45–64	0 (81)	...	3.3 (92)	...	1.7 (173)	...
Totals	6.3 (1,901)	0.07 (2,923)	6.9 (1,784)	0.97(2,587)	6.6 (3,687)	0.49(5,510)

For purposes of comparison we have inserted in Fig. 10 and 11 data on *Sphyrion* infestation of redfish in the Gulf of Maine and Nova Scotian Shelf areas obtained during the United States investigations of January, 1938 to February, 1939. The degree of *Sphyrion* infestation in these areas has been indicated generally by Nigrelli and Firth (1939) and in more detail by Herrington *et al.* (1939). Our United States data for Fig. 9, 10 and 11 have been obtained from the latter authors. In these United States data all *Sphyrion* parasites as well as secondary externally visible effects were included, such as sores which may have been caused by an attached parasite, and raised areas due to encysted old heads of dead *Sphyrion*. From the figure of parasite positions given by Herrington *et al.* it is indicated that *Sphyrion* parasites made up about 60% and sores, etc., about 40% of the total. Thus to compare with our figures which are of parasites

only, the data of these authors should be reduced to 60% of their totals. In our Fig. 10 and 11 therefore, all infection percentages etc. (except parasites per infected fish) have been reduced to 60% of the original values of Herrington *et al.* It has not been possible to apply corrections for the data of these authors on parasites per infected fish, and these data in Fig. 11 include both parasites and sores etc. and are thus higher than they would be if, as in our own data, external *Sphyrion* parasites, only, had been recorded.

When thus treated it is evident that the level of *Sphyrion* infestation in the redfish population of the coastward part of the Gulf of Maine is approximately the same as that in the area showing the highest infestation level in the Canadian area, i.e. east of Hamilton Inlet Bank off Labrador. In the Gulf of Maine area, as off southern Labrador, there are the same great changes within very short distances in the amount of infestation of redfish by *Sphyrion lumpi.*

It is difficult to find an explanation for the presence of high *Sphyrion* infestation in the two widely separated Hamilton Inlet Bank and Gulf of Maine areas, with areas of much lower infestation and even of no apparent infestation between them. The Hamilton Inlet Bank area of high infestation is at the northern limit of the presently known areas of high redfish abundance. In this area redfish can only rarely encounter temperatures as high as 4°C. The Gulf of Maine area of high infestation is certainly the southernmost area of redfish abundance and temperatures in redfish depths are at times as high as 6 to 8°C. Temperatures in redfish depths in the areas between these two centres of high infestation by *Sphyrion* are in general intermediate between these two extremes. The southwestern slope of the Grand Bank possesses variable temperatures in redfish depths sometimes lower than Labrador, often as high as or even higher than the Gulf of Maine and yet *Sphyrion* infection of redfish is extremely rare in this area. It is highly unlikely, therefore, that variations in temperature within the limits 3 to 6 to 8°C are in any way responsible for differences in the abundance of *Sphyrion*. On the other hand it is barely possible that at the northern and southern extremes of abundant redfish populations the resistance of the redfish to infection by *Sphyrion* is lowered, but we would regard this as unlikely. (For a discussion of the relationship between temperature and abundance of redfish see Templeman, 1959.)

Variations in salinity appear to offer no explanation for the *Sphyrion* distribution.

INFESTATION AND DEPTH. The present data are in the main a study of *Sphyrion* infestation of redfish down to slightly over 200 fathoms (365 m) since this was the usual depth limit of the otter-trawling gear used by the Fisheries Research Board's research vessel, the *Investigator II*, during the period of the investigation. Some slightly deeper records were obtained from catches by commercial vessels. Thus, although the complete depth distribution of *Sphyrion* cannot be presented, Table II indicates that there is a greatly increased abundance of *Sphyrion* on the eastern Grand Bank at 201–220 fathoms (368–402 m) and in the Gulf of St. Lawrence and Laurentian Channel at 196–200 fathoms (358–366 m).

The Labrador data indicate that the abundance is greater at 162–212 fathoms (296–388 m) than at 135–142 fathoms (247–260 m).

Subsequent investigations, to be reported on later (see also, Templeman, 1955), have shown that *Sphyrion* infestation of redfish has a strong depth relationship.

TABLE II. *Sphyrion lumpi* infestation in redfish in relation to depth (1949–1953).

Depth range	Redfish examined	Redfish parasitized by *Sphyrion*	*Sphyrion* per 100 redfish	*Sphyrion* per infested fish
fath. (*m*)	*No.*	%	*No.*	*No.*
		Labrador		
135–142 (247–260)	142	0.70	2.11	3.00
162–170 (296–311)	533	6.57	9.20	1.40
178–180 (326–329)	1,617	6.61	9.35	1.41
198–212 (362–388)	2,119	6.09	8.65	1.42
		Eastern Grand Bank		
51–80 (93–146)	154	0	0	0
81–110 (148–201)	204	0.49	0.99	2.00
111–140 (203–256)	5,157	0.29	0.31	1.07
141–170 (258–311)	6,699	0.34	0.40	1.17
171–200 (313–366)	4,351	0.16	0.16	1.00
201–220 (368–402)	987	3.95	4.96	1.26
		Gulf of St. Lawrence and Laurentian Channel		
84–85 (154–155)	373	0	0	0
98–120 (179–220)	1,683	0.06	0.06	1.00
140–160 (256–293)	1,188	0.34	0.34	1.00
163–180 (298–329)	759	0.40	0.79	2.00
196–200 (358–366)	389	1.29	1.80	1.40

It is apparent even from the small amount of data available on the relationship of depth to abundance of *Sphyrion lumpi* that not until data on *Sphyrion* abundance have been gathered throughout the whole redfish depth range will the information on the distribution of *Sphyrion* by locality be fully adequate.

Sphyrion LIFE-HISTORY AND LOCALIZATION OF *Sphyrion* INFESTATION OF REDFISH. Krøyer says that the young *Sphyrion lumpi* in the egg is 0.4 mm long. Nigrelli and Firth (1939) state that they have found young *Sphyrion*, 2 mm in length, embedded under the epidermis of the redfish of the Gulf of Maine. Also the male found by Wilson (1919) was 2 mm long. At any usual rate for crustacean growth there should be a few stages between the larvae and these settled forms.

Heavy infestation by the adult female parasites is so localized by area and depth and in such distinctly separated localities that we must assume that the adult female *Sphyrion* in these areas developed from larvae produced by these same localized populations. Since usually in passing through several stages

the young parasites would drift significantly and be distributed at various depths, it is difficult to believe that they would maintain populations in the same horizontal and vertical locations if they were not either free swimming and were returned to the same relative position by an eddy whose period of circulation corresponded to the free-swimming period of the larva, or if they did not have an intermediate host with sedentary or restricted migratory habits and localized by depth. It is also a possibility that the female *Sphyrion* larva moults into a copepodid stage after hatching and soon settles on a redfish at a size smaller than has been observed up to the present.

Sphyrion lumpi, like *Lernaeocera branchialis* (L.) may have an intermediate host between the early free-swimming stages and the stage, still free swimming, in which the female settles on the redfish. In this case centres of abundance may be related not only to the abundance of the final host, the redfish, but also to the abundance of the intermediate host. Although the faunal distribution of the area generally has not been studied extensively, the distribution of the fishes at least is fairly well known to us and it is extremely difficult to believe that an abundance of any intermediate host could exist seaward of Hamilton Inlet Bank and in the shoreward part of the Gulf of Maine and not in some of the in-between areas.

Dead *Sphyrion*, Internal

The data on the occurrence of dead and usually hard, brown *Sphyrion* heads in fillets (Fig. 12 and 13) were collected after all heads of whole *Sphyrion* of the present generation had been removed. These data, also, do not include the evidence of former *Sphyrion* infection in the cloaca, belly, head, pectoral and pelvic fins. Also, depending on the filleter, some of the old heads very close to the dorsal and anal fins and those close to the vertebral column also may not be included in the fillet.

In spite of this the redfish lives to such a considerable age that where sufficient *Sphyrion* infestation occurs there is a considerable accumulation of these old heads in the fillets. Not only is this so east of Hamilton Inlet Bank, but it is apparent also in what appeared (from the information on abundance of living *Sphyrion*) to be centres of considerably less infestation: namely, the southern part of the eastern slope of the Grand Bank and the southeastern part of the Laurentian Channel near Cape Breton. It is very likely that in the various centres of infestation by *Sphyrion* there are abundant and poor year-classes of *Sphyrion* surviving up to the point of infestation of the redfish. Thus observation of living *Sphyrion* over a number of years is necessary as well as more data on the accumulation of old dead heads in the flesh. On the other hand, the data on old heads as well as on living *Sphyrion* show no infestation on the Nova Scotian Shelf.

Because once the old heads become hardened and encysted in the flesh they should not disappear, it is to be expected that in an area the degree of infestation,

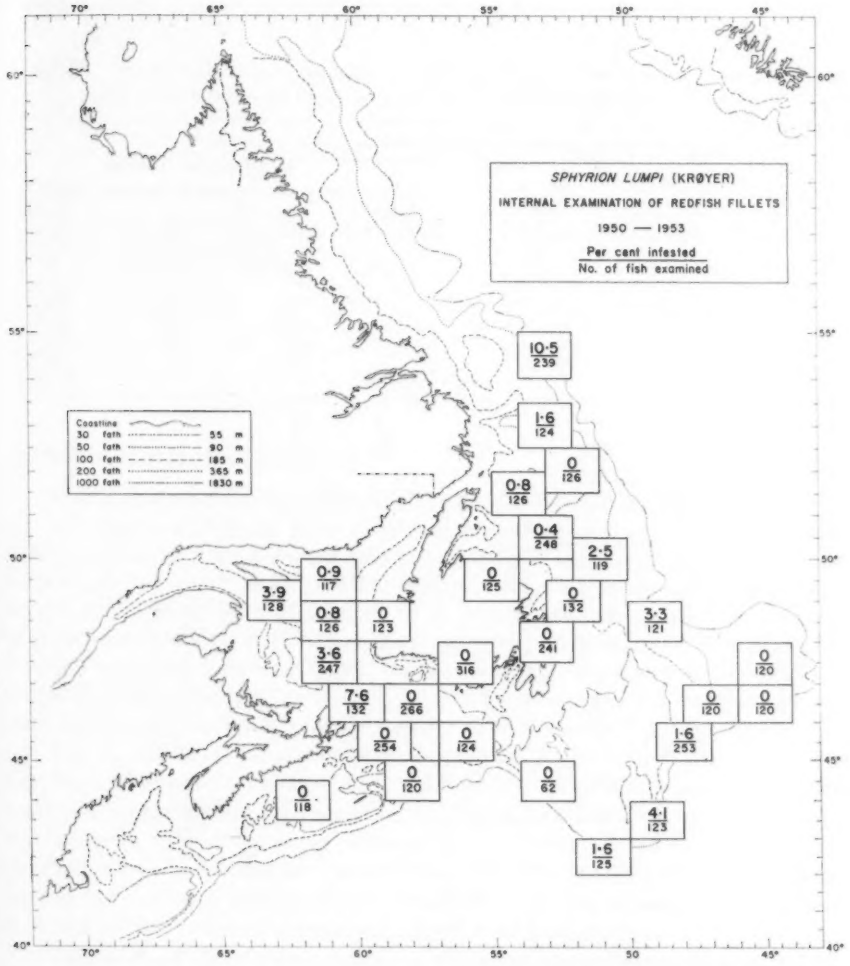

FIG. 12. Percentages of redfish in various parts of the Canadian sector of the Northwest Atlantic containing old dead heads of *Sphyrion lumpi* in their fillets. (All heads of the present recently living generation of *Sphyrion lumpi* had previously been removed.)

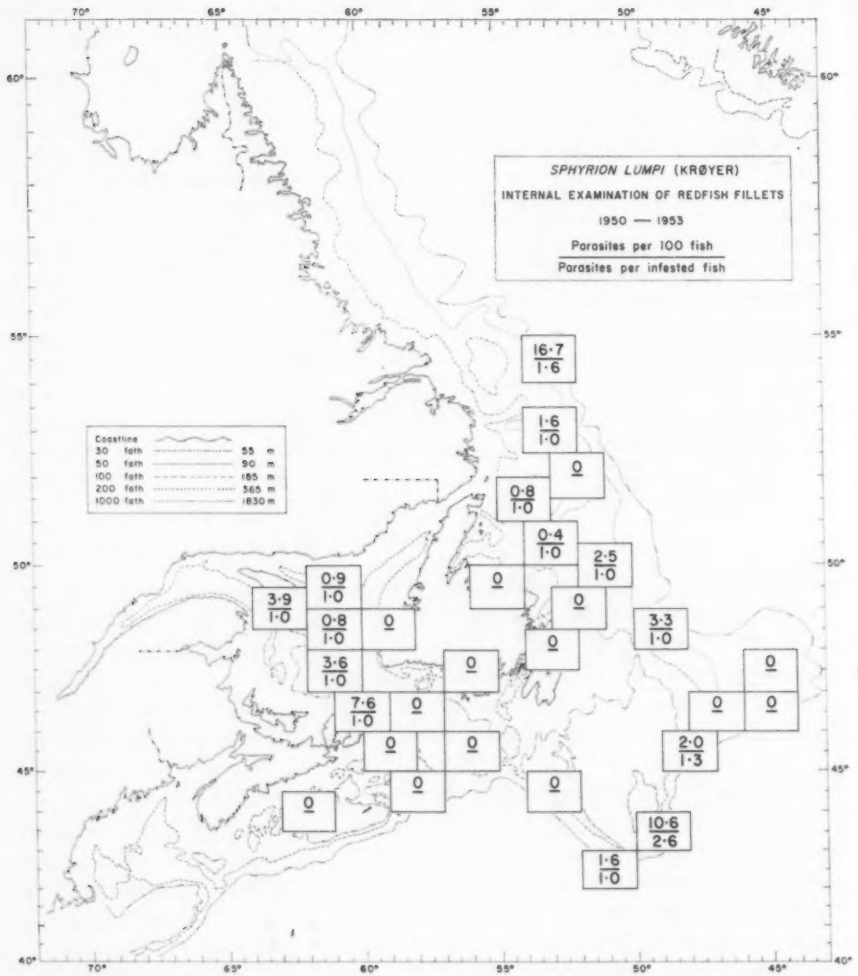

FIG. 13. Numbers of old dead heads of *Sphyrion lumpi* (in fillets) per 100 redfish, in various parts of the Canadian sector of the Northwest Atlantic and the numbers of old heads per infested fish in these fillets. (All heads of the present recently living generation of *Sphyrion lumpi* had previously been removed. Numbers of fish in samples are identical with those in Fig. 12.)

indicated by old heads, would increase with size of fish. To some degree this is the case in our data (Table III) but the small number of individuals for which complete detail is available make for some irregularity in the results.

TABLE III. Internal evidence of old heads of *Sphyrion lumpi*. (The numbers of redfish whose fillets were examined are shown in parentheses. Redfish lengths as in Table I.)

Redfish length range	Percentage of redfish with fillets containing *Sphyrion* old heads					
	Male			Female		
	Labrador	Eastern Grand Bank	Gulf of St. Lawrence	Labrador	Eastern Grand Bank	Gulf of St. Lawrence
cm	%	%	%	%	%	%
14–29	...	...	0 (36)	...	...	0 (25)
20–29	1.2 (84)	0 (53)	...	4.2 (72)	0 (33)	...
30–34	2.7 (114)	0 (115)	1.0 (105)	7.5 (40)	1.8 (110)	0 (5)
35–39	5.9 (102)	4.3 (23)	...	7.4 (68)	6.0 (117)	5.7 (157)
40–59	...	...	...	2.5 (121)	2.0 (49)	6.1 (98)
35–59	...	...	2.5 (321)	...	...	...

Sphyrion AND REDFISH MIGRATION

It was obvious from the United States studies by Herrington *et al.* (Fig. 10, 11) that there could be no rapid migration of redfish between the western Gulf of Maine areas of high *Sphyrion* infestation and the neighbouring Browns Bank areas where *Sphyrion* infestation did not occur. Similarly in our data in the above figures, if *Sphyrion* has a life history of at least a few months there is unlikely to be rapid migration of redfish from the Hamilton Inlet Bank area. More definite evidence regarding long-term migration is provided by the distribution of redfish containing dead *Sphyrion* heads (Fig. 12, 13). These old heads represent in the older fish the accumulation of many years. By comparing Fig. 10 with Fig. 12, and Fig. 11 with Fig. 13, it will be noted that in the Hamilton Inlet Bank and Northeast Newfoundland Shelf area, although the maximum abundance of old heads is in approximately the same location as the abundance of living *Sphyrion*, the old heads offer either some evidence of a migration of redfish southward in the direction of the Labrador Current along the Northeast Newfoundland Shelf toward the northern border of the Grand Bank or the presence in the latter area of a former centre of infestation. Both may have occurred.

The old-head abundance indicates very little movement of the infested redfish from the minor centre of infestation on the southeastern Grand Bank.

In the Laurentian Channel of the Gulf of St. Lawrence the old-head abundance, compared with the abundance of living *Sphyrion*, indicates the possibility of slow migration of redfish, formerly infested by *Sphyrion*, westward along the Laurentian Channel toward Gaspé and the mouth of the St. Lawrence estuary but not southeastward out of the Gulf of St. Lawrence. It appears likely that the redfish are assisted in their inward movement by the inward passage of the deep water. This deep water passes westward into the Gulf to

replace the more superficial layers of sea water used up in the mixing with fresh water in the estuary of the St. Lawrence River to form the outgoing more superficial mixed water of the Gaspé Current.

Because, however, of the strong relationship between depth of water and amount of *Sphyrion* infestation, and since the largest and presumably oldest redfish of the *mentella* and presumably also the *marinus* types tend gradually to reside in deeper water, it will be necessary to include depth relationships for any rigorous demonstration, based on *Sphyrion* infestation, of migration or lack of migration of redfish. There is no definite depth information regarding the Gulf of Maine data but the heaviest infestations, even if they occurred in shallow water, were probably related to the vicinity of deep water in the inner channels of the Gulf of Maine. The uninfested Brown's Bank redfish are most likely from shallow water of 50–100 fathoms (90–185 m), in which depths redfish infested by *Sphyrion* are scarce in the Newfoundland area also.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the assistance in sea and shore observations by many biologists and technicians, particularly by R. Knapp-Fisher, the late G. L. Handrigan and by A. G. Kelland, C. I. Barbour and L. N. Cluett. The photography is by E. L. Rowe.

REFERENCES

BASSETT-SMITH, P. W. 1899. A systematic description of parasitic copepoda found on fishes, with an enumeration of the known species. *Proc. Zool. Soc. London*, 1899, pp. 438–507.

BIOLOGICAL STATION, ST. JOHN'S, NFLD. 1951. In *Ann. Rep. Fish. Res. Bd. Canada* for 1950, pp. 26–38.

CUNNINGHAM, R. O. 1871. Notes on the reptiles, amphibia, fishes, mollusca, and crustacea obtained during the voyage of the H.M.S. Nassau, 1866–1869. *Trans. Linn. Soc. London*, **27**: 465–501.

HANSEN, H. J. 1923. Crustacea copepoda II. Copepoda parasita and hemiparasita. *Repts. Danish Ingolf-Expedition*, **3**(7): 1–92.

HERRINGTON, WILLIAM C., HENRY M. BEARSE, AND FRANK E. FIRTH. 1939. Observations on the life history, occurrence, and distribution of the redfish parasite *Sphyrion lumpi*. *U.S. Bur. Fish., Special Sci. Rep.*, No. 5, pp. 1–18.

KRØYER, H. 1845. *Lestes lumpi* Krøyer. *Danmarks Fiske*, Vol. 2, p. 517.

1863. Bidrag til Kundskab om Snyltekrebsene. *Naturh. Tidsskr.*, Ser. 3, **2**: 75–426.

LEIGH-SHARPE, W. HAROLD. 1928. The genera *Sphyrion* and *Basanistes* (copepoda) as represented by the collection in British Museum. *Parasitology*, **20**: 179–184.

LÜLING, K. H. 1951. Neuere Untersuchungen über die Parasiten des Rotbarsches: *Sebastes marinus* (L.). *Z. f. Parasitenkunde*, **15**: 8–24.

MEYER, ARNO. 1951. Keine Fischmarkierung sondern ein Parasit. *Fischereiwelt*, **5**: 76–77.

NIGRELLI, ROSS F., AND FRANK E. FIRTH. 1939. On *Sphyrion lumpi* (Krøyer), a copepod parasite on the redfish, *Sebastes marinus* (Linnaeus), with special reference to the host-parasite relationships. *Zoologica*, **24**(1): 1–10.

PERLMUTTER, ALFRED. 1951. The positional pattern of the copepod parasite *Sphyrion lumpi* on the rosefish, *Sebastes marinus*, and its relationship to the behaviour of the fish. *Copeia*, 1951, No. 1, pp. 97–98.

SCOTT, THOMAS. 1901. Notes on some parasites of fishes. *Ann. Rept. Fish. Bd. Scotland*, No. 19, (3) pp. 120–153.

1905. Observations on some parasites of fishes new or rare in Scottish waters. *Ibid.*, No. 23, (3) pp. 108–119.

SCOTT, THOMAS, AND ANDREW SCOTT. 1913. The British parasitic copepoda. Vol. 1: Copepoda parasitic on fishes, *Sphyrion lumpi* (Krøyer), pp. 164–166. Vol. 2: Plates. The Ray Society, London, England.

STEENSTRUP, J. 1869. Om *Lesteira*, *Silenium* og *Pegesimallus*, tre af Prof. Dr. H. Krøyer opstillede Slaegter af Snyltekrebs. *Overs. Kongel. Danske Vidensk. Selsk. Forhandl.*, 1869, No. 3, pp. 179–202.

STEPHENSON, K. 1940. Parasitic and semiparasitic copepoda. *Zool. Iceland*, **3**(34): 1–24.

TEMPLEMAN, WILFRED. 1953. Knowledge of divisions of stocks of cod, haddock, redfish and American plaice in Subareas 3 and 2 of the Northwest Atlantic Convention area. *Int. Comm. NW Atlantic Fish., Ann. Proc.*, **3**: 62–66.

1955. Canadian researches, 1954; Subarea 2 (ICNAF); redfish, *Sebastes marinus* (L.). *Ibid.*, **5**: 19–20.

1959. Redfish distribution in the North Atlantic. *Fish. Res. Bd. Canada, Bull.*, No. 120, pp. 1–173.

WILSON, C. B. 1919. North American parasitic copepods belonging to the new family Sphyriidae. *U.S. Nat. Mus., Proc.*, No. 55, pp. 549–604.

1932. The copepods of the Woods Hole region, Massachusetts. *U.S. Nat. Mus., Bull.*, No. 158, pp. 1–635.

Estimating Abundance from Longline Catches[1]

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ABSTRACT

The various factors that enter into the catch of fish by a baited longline are combined into equations that permit using the information afforded by the catches to compute linear estimates of abundance, providing that all rates can be estimated reasonably accurately, and assuming they are linear. The equations also serve to show the catches of a baited longline have a maximum in contrast to the asymptote of gill net catches. In practice, application of the suggested methods may not result in precise estimates of abundance, but they will serve to indicate the degree of confidence to be placed on the catch data and what precautions must be observed in interpreting the data, and they may serve to develop knowledge of the behaviour of a species. This knowledge, together with the knowledge of the several rates involved, may serve as a basis for examining fishing tactics.

INTRODUCTION

Of the several common methods of harvesting fishes, the one that furnishes the most disarmingly simple results in terms of catch per unit of effort is the baited longline. Longline fisheries provide results in terms of catch in weight or numbers per hook or some standardized multiple of the hook. Generally, these indices are accepted and used as linear estimates of abundance. Gulland (1955) and Beverton and Holt (1957) considered that such statistics were not valid unless they were corrected for gear saturation. It is the purpose of this discussion to extend their treatment of longline catches.

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THE CATCH EQUATION

A more elaborate and at the same time more generalized equation that can account for all of the variables affecting the catch may be developed as follows:

Let

X = number of baits undisturbed

Y = number of fish hooked (whether or not they subsequently escape)

Z = catch (number of fish on the line at a given time)

A = total number of hooks

a = instantaneous rate of loss of bait from all sources excluding b, e.g. catching undesirable species, bait dropping off, etc.

b = instantaneous rate of hooking fish

c = instantaneous rate of loss of hooked fish

$$\frac{dX}{dt} = -aX - bX$$

$$\therefore X = Ae^{-(a+b)t} \tag{1}$$

$$\frac{dY}{dt} = bX$$

$$\frac{d(Y-Z)}{dt} = cZ$$

$$\frac{dZ}{dt} = -cZ + bX$$

$$\frac{dZ}{dt} = -cZ + bAe^{-(a+b)t}$$

$$\int \frac{d}{dt}(e^{ct}Z)dt = \int bAe^{(c-a-b)t}dt$$

$$e^{ct}Z = \frac{bA}{c-a-b}e^{(c-a-b)t} + K.$$

At $t = 0$, $Z = 0$:

$$\therefore e^{ct}Z = \frac{bA}{c-a-b}(e^{(c-a-b)t} - 1)$$

$$\therefore Z_t = A\left[\frac{b}{c-a-b}(e^{-(a+b)t} - e^{-ct})\right] \tag{2}$$

If rates a and c are set to zero, equation (2) above is identical to Gulland's equation (2.10).

t for maximum Z, or t_{Z_m}, can be derived from equation (2) above.

Let $c \neq a + b$.

$$\therefore \frac{dZ}{dt} = \frac{Ab}{c-a-b}\left[-(a+b)e^{-(a+b)t} + ce^{-ct}\right] = 0$$

$$e^{(c-a-b)t} = \frac{c}{a+b}$$

$$\therefore t_{Z_m} = \frac{1}{c-a-b}\left(\log_e \frac{c}{a+b}\right) \tag{3}$$

In practice the various rates can be estimated if one end of the line has a significantly longer fishing time than the other, and if records are made of the status of each hook as the line is hauled. Though not especially efficient, the easiest approach is to estimate Z for any two points on the line that do not include a maximum, estimate $a + b$ independently from the record of undisturbed bait returns, and set up two simultaneous equations with respect to Z. The rate b can then be determined in terms of the rate c and substituted in one of the equations which on simplification yields a polynomial in c. Taking the first derivative of the polynomial and setting it to zero solves for c, or alternately c may be obtained by a rather rapid iteration. The rest is straightforward algebraic manipulation.

Equation (2), in addition to taking more factors into account, is more appealing than Gulland's equation 2.10 because it separates the baited longline from the gill net by permitting the catch to fall towards zero if the line is left out long enough, and provides for a time of maximum catch. Gulland's equation does not so provide, and is therefore not appropriate for baited longlines, though it appears appropriate for gill nets and unbaited longlines, because any loss of catch may automatically restore the fishing power to these gears. The gill net does not necessarily lose fishing power in any way analogous to the loss of bait from the longline, unless the net fills up with unwanted species or becomes badly tangled on each contact with a fish. Thus the catch of a gill net and unbaited longline should generally approach an asymptote, and the catch of a baited longline should have a maximum.

In practice it is impossible to obtain complete statistics on a longline fishery. A reasonable sample should however serve to give an estimate of the various rates involved and thus permit the investigator to adjust his statistics and/or indicate the amount of caution needed in their interpretation. For example, a series of 23 tuna longline stations of 240 hooks each conducted by the Pacific Oceanic Fisheries Investigations in Hawaii with catch rates ranging from 1.50 to 2.49 yellowfin tuna per 100 hooks yielded the following estimates:

Fishing time = 330 minutes for gear first hauled on board, and 590 minutes for the last gear on board.

Time of maximum catch (t_{Z_m}) = 19.0 hours (not realized in practice because the gear was set at dawn and hauling commenced at noon, all line being in about 4:00 p.m.).

Instantaneous rate of loss of bait (a) = 0.048 (hourly basis).

Instantaneous rate of hooking (b) = 0.004 (hourly basis).

Instantaneous rate of fish loss (c) = 0.048 (hourly basis).

Simple inspection of these rates suggests that variation in the catches within their order of magnitude will be only slightly affected by gear saturation because all of them are low, and that the unadjusted catches may be used as indices of abundance for most purposes.

SOME IMPLICATIONS OF EQUATION (2)

Equation (2) clearly shows that the longline catch does not increase linearly as the hooking rate increases; rather, the gear catches a smaller proportion of the population in unit time as the number of fish on the grounds increases. It follows that catches expressed in terms of weight per unit of gear are not comparable among themselves unless the fish are of equal sizes, because small fish make the same contribution to gear saturation as large fish.

For this reason a management practice that redistributed the total population from many small fish to fewer large ones, or vice versa, would result in exaggerated indications of changes in stock magnitude if the criterion of stock magnitude is weight per set of gear. The degree of erroneous assessment from this source of error (either up or down) would be a function of the numerical catch per standard unit of gear. In this context the average catch per set does not necessarily indicate whether or not saturation is important, for it is the high catches that contribute most to the saturation effect as well as to the average catch. Statistics from a fishery in which one fourth of the catches were high and three-fourths zero would be just as much biased as statistics from a fishery in which all catches were high.

A hypothetical example of the effect of a change in size of fish on the catch is as follows:

Initially let $a = 0.05$, $b = 0.20$, and $c = 0.05$ (on an hourly basis). Then $t_{Z_m} = 8$ hours and $Z_8 = 55$ fish per 100 hooks. Now if the number of fish on the grounds is halved and their individual weight doubled, and it is assumed that large fish do not forage more widely than small fish, the hooking rate (b) will be reduced to 0.10 and $Z_8 = 38$ fish per 100 hooks, but since the fish are twice as heavy the catch by weight per hundred hooks is now 1.4 times as large.

Independent of saturation, but related to saturation in that the effects may be in the same direction, are two other possibilities associated with size of fish. The example above assumes the hooking rate (b) is inherently the same for small and large fish. This seems unlikely, firstly, because hook gear is generally tailored to the larger fish expected on the grounds, and secondly, hooking rate must be in part a function of the activity of the fish and large fish might well forage over a larger area in unit time. These latter factors are not unique to catches expressed

in terms of weight, but they would generally appear to operate in the same direction as the saturation factor, that is tending to cause underestimation of the stock if the individuals are small, and overestimation of the stock if the individuals are large. The magnitude of the cumulation of such errors may or may not be significant in a particular fishery, but it obviously can be significant and must be ascertained if the catches (especially when expressed in weight units) are to be utilized as indices of stock magnitude.

OTHER FACTORS

The existence of time-specific changes in the basic rates was brought home by a second set of tuna catch data shown in Fig. 1. Though the points show an increasing catch with fishing time, a maximum, and the expected decline, it is impossible to obtain a fit using equation (2), primarily because the ascending limb of the curve suggests an accelerating rather than a decelerating rate of accumulation of fish and no reasonable fit can be projected back to the zero-zero

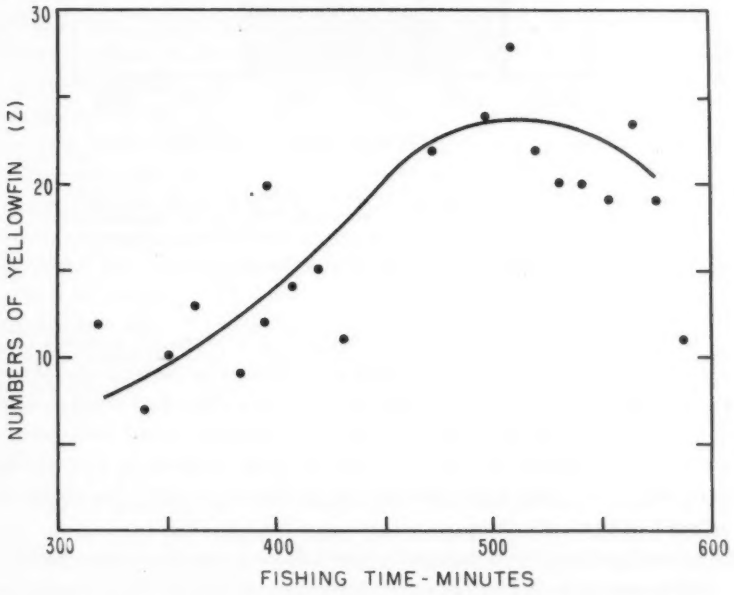

FIG. 1. Relation of catch (Z) to fishing time (t) for a series of 23 stations having raw catches ranging from 5 to 7 per 100 hooks. Each point represents the catch of 276 hooks plotted against the mean fishing time for each group. The curve is fitted by hand. The gear was set about dawn and hauling commenced about noon.

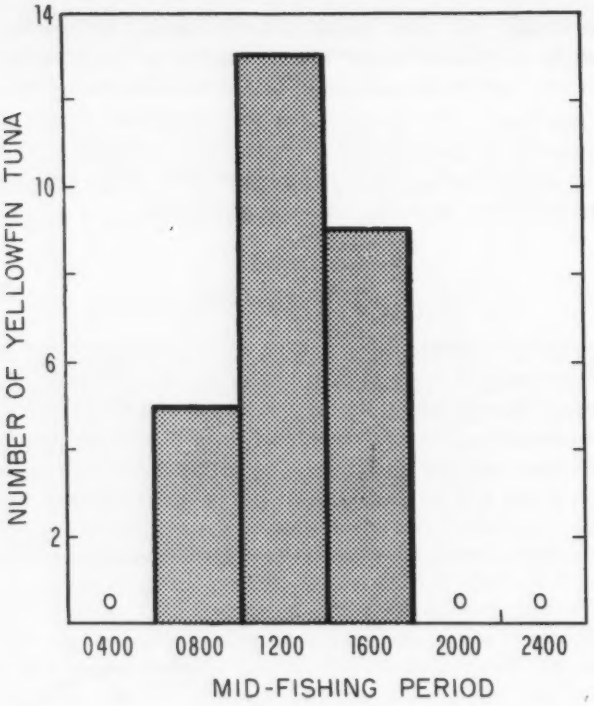

FIG. 2. Summed catches of 5 special longline stations. At each station 10 baskets of 6-hook gear were fished for 6 periods of slightly less than 4 hours. The midpoint of each 4-hour fishing period was approximately as indicated on the abscissa.

origin. These data, together with the results of a few special stations (Fig. 2), show that the rate of hooking (b) was probably increasing through mid-afternoon. This was not evident in the series of low catch stations described above, suggesting that in some circumstances behaviour is an important factor associated with differences in catch rates. In this example it is not possible to fit equation (2) but an attempted fit serves to indicate the existence and the magnitude of the effect of such behaviour factors.

Factors other than the behaviour of the fish may also vary significantly with time. For instance, bait loss (a) may not remain constant. This easily can be determined by field observations. The biting rate (b) might be affected by loss of bait quality with time, a factor also susceptible to test, and the rate of loss of hooked fish (c) might vary with time considering an individual fish. However in a situation in which fresh fish are being continuously added to the line, i.e.,

during periods when the activity of the fish remains high and before saturation is reached, this rate should remain relatively constant.

Gulland (1955) suggests that schooling will interfere with corrections based on his equations (2.10), and of course the same comment would apply to equation (2) of this discussion. However, it appears that if school size remains relatively constant there will not be distortion of the catch per unit of effort as an index of abundance, because the effective unit is simply shifted from the individual to some multiple of the individual.

Some knowledge of the existence of the schooling problem can be rather easily obtained. For example, Murphy and Elliot (1954) concluded from direct evidence of contagion (in the spatial distribution of the fish along the line), and from the nature of the catch variability, that longline-caught tuna showed evidence of slight aggregation. Following this lead the hook density was experimentally increased from 6 to 11 hooks per 1200 feet of mainline on half of the baskets. These modified baskets, alternated in the sets (Shomura and Murphy, 1955), took 1.21 times as many yellowfin as the unmodified gear. If the fish are singly and randomly distributed, increasing the hooks should affect equation (2) by reducing b and perhaps a and increasing Z, that is, in effect reducing the saturation factors, but any reasonable tinkering with the pertinent average rates (the uncorrected catches were about 4 per 100 hooks) cannot account for more than $\frac{1}{10}$ of the increased catch. The bulk of the increase therefore stems from reduction of localized saturation as proposed by Gulland, or stated differently, the catch per school encountering the line was increased by about 20%. This is quite compatible with the degree of contagion detected by Murphy and Elliot (1955), but in no way affects intercomparisons utilizing standardized gear so long as school size remains reasonably constant.

Gulland's final caution relates to the possibility that territoriality might tend to preclude saturation. This seems unlikely for pelagic fish, but might apply in demersal fisheries. This problem is subject to ready evaluation by the same experimental methods that revealed a moderate schooling effect with respect to yellowfin tuna.

CONCLUSIONS

Though utilizing raw catch statistics from line fisheries as indices of abundance involves a number of uncertainties, these uncertainties can be resolved if appropriate observations are made on the line as it is set and hauled, and if proper experimental fishing is conducted. The latter, as well as serving to assist the interpretation of the catch statistics, will provide valuable indirect knowledge on the behaviour of the species in question. Unfortunately, it appears likely that in many, if not in most, instances, it will not be practical to precisely correct for the various factors affecting Z, in order to arrive at an unbiased index of

abundance on a routine basis. On the other hand it does appear possible to identify and to estimate the relative magnitude of the various effects enabling the investigator to either disregard them as minor, make approximate corrections, or simply utilize the knowledge in a cautionary way when interpreting the data. The information developed in the course of ascertaining the degree of saturation, time of maximum catch, time-specific changes in biting rate, etc., are as applicable to the problem of developing fishing tactics as they are to interpreting catch data as estimates of population parameters.

ACKNOWLEDGMENTS

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REFERENCES

BEVERTON, R. J. H., AND S. J. HOLT. 1957. On the dynamics of exploited fish populations. *U.K. Min. Agric., Fish. and Food, Fishery Investigations*, Ser. II, **19**, 533 pp.

GULLAND, J. A. 1955. Estimation of growth and mortality in commercial fish populations. *U.K. Min. Agric. Fish. and Food, Fishery Investigations*, Ser. II, **18**(9), 46 pp.

MURPHY, G. I., AND K. C. ELLIOT. 1954. Variability of longline catches of yellowfin tuna. *U.S. Fish and Wildlife Serv., Special Sci. Rept., Fisheries*, No. 119, pp. 1–30.

SHOMURA, R. S., AND G. I. MURPHY. 1955. Longline fishing for deep-swimming tunas in the Central Pacific, 1953. *U.S. Fish and Wildlife Serv., Special Sci. Rept., Fisheries*, No. 157, pp. 1–70.

The Growth, Length–Weight Relationship, and Maturity of Haddock (*Melanogrammus aeglefinus* L.) from the Region of Lockeport, N.S.[1,2]

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ABSTRACT

Data from samples of commercial landings of inshore Lockeport haddock are used to form a curve of growth in length. Maturity and spawning data for these fish are then related to changes in their length–weight relationship. By combining length–weight and growth-in-length data, a curve of growth in weight is derived for use in yield calculations. Apparent changes in growth of inshore Lockeport haddock between 1926 and 1946–54 are discussed.

INTRODUCTION

In an earlier paper (Kohler, 1958) the validity of the otolith aging method for Lockeport haddock was demonstrated. By examination of additional sampling data accumulated during the years 1946–1954, information was obtained on growth, length–weight relations, and maturity for these fish. This information is presented and apparent changes in the growth pattern at Lockeport are discussed.

GROWTH IN LENGTH

Source of Data

All data used in the study of growth have been taken from samples of commercial landings of haddock at Lockeport from the inshore grounds of the area. Methods of sampling, weighting of samples, and the area concerned have been described in a previous paper (Kohler, 1958). Growth calculations for these haddock were complicated somewhat by selection in sizes of fish sampled. The cull for sizes acceptable for commercial purposes resulted in the discard by fishermen of haddock less than about 40 cm in length. Most of these small fish were eliminated from the catch by the use of hook sizes which have been shown to take few haddock under commercial size (McCracken, 1957). The result was that the length distributions of sampled age-groups up to about 4 years of age were biased towards greater lengths.

The available age–length data (age in years completed) have been summarized by quarters of the year (Appendix Table A). In the Table mean lengths are given at the bottom of the frequency column together with their standard deviations and the weighted number of fish per age-group (for an

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[2]Based on part of a thesis accepted by the Faculty of Graduate Studies and Research, McGill University, in partial fulfilment of the requirements for the degree of Master of Science in Zoology.

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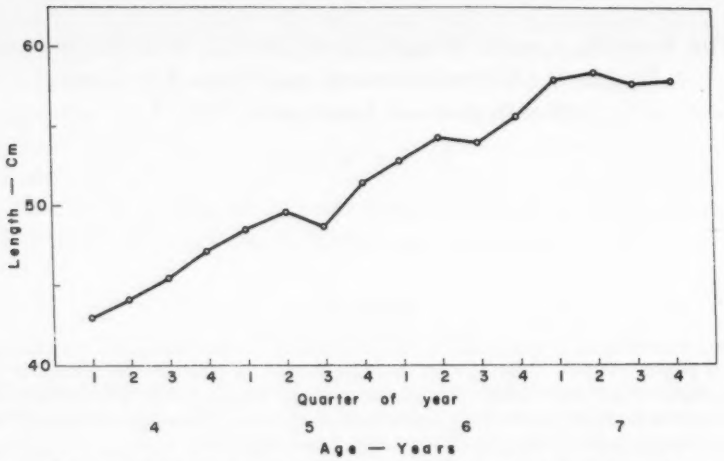

FIG. 1. Quarterly increments of growth in length of Lockeport haddock.

explanation of weighting factors, refer to Kohler, 1958). Sampling intensity was not equally spread over the four quarters or over the years 1946 to 1954. Thus, when some of the data were plotted by quarterly increments (Fig. 1) certain irregularities in the line were noted. The most noticeable of these are the low average means in the third quarter for 5- and 6-year-olds. These could be related to onshore movements of haddock (McCracken, 1956) although length-at-age of offshore haddock in the area (Wise, 1957) can be shown to average only about 1 cm less. The irregularities are further exaggerated because of slightly higher than normal second quarter mean lengths plotted from data about 50% of which was taken from 1943 and 1948 year-class specimens. These

TABLE I. Mean lengths in centimetres of age-groups of haddock sampled from landings of inshore Lockeport catches from 1946 to 1954. Decimal fractions appear as a result of the use of weighting factors (Kohler, 1958).

Sampling quarter		Age 3	4	5	6	7	8	9	10	11	12	13	14	15
Feb.–Apr.														
No. of fish	n	...	115.09	190.76	130.29	53.99	22.33	6.53	7.95	5.75	4.89	2.98	5.93	3.94
Mean length	$\bar{x}$	...	43.1	48.6	52.9	57.9	60.3	61.0	64.6	63.4	67.5	63.6	69.4	69.4
Standard deviation	$S_{\bar{x}}$	...	0.36	0.32	0.40	0.57	0.80	2.36	1.87	1.29	1.88	1.76	1.22	3.45
May–July														
No. of fish	n	...	20.78	97.60	37.22	30.96	17.16	16.56	10.32	4.76	3.22	3.34	...	...
Mean length	$\bar{x}$	...	44.2	49.7	54.3	58.4	59.1	61.2	63.4	70.8	63.6	63.7	...	...
Standard deviation	$S_{\bar{x}}$	...	0.98	0.63	0.88	0.85	1.35	1.44	2.11	2.28	0.60	0.78	...	...
Aug.–Oct.														
No. of fish	n	...	92.17	96.32	92.18	39.67	33.80	24.07	5.08	4.82	2.16	2.08	2.00	2.94
Mean length	$\bar{x}$	...	45.5	48.6	53.8	57.6	61.3	61.9	64.0	69.5	65.4	62.9	67.5	75.9
Standard deviation	$S_{\bar{x}}$	...	0.46	0.33	0.48	0.83	0.69	0.71	2.03	1.81	1.39	4.31	1.50	4.50
Nov.–Jan.														
No. of fish	n	122.79	251.72	297.08	169.65	124.26	43.92	32.34	16.17	19.30	6.07	2.00	...	...
Mean length	$\bar{x}$	43.0	47.2	51.5	55.6	57.7	60.8	63.3	63.4	63.7	70.2	67.5	...	...
Standard deviation	$S_{\bar{x}}$	0.40	0.10	0.26	0.37	0.39	0.66	0.85	0.94	1.43	1.67	0.71	...	...
Average for year		43.0	45.0	49.7	54.2	57.9	60.4	61.9	63.8	66.8	66.7	64.4	68.4	72.6

two relatively abundant year-classes (Kohler, 1958) had mean lengths higher than the usual average. Thus, we were led to the view that the irregularities in Fig. 1 were mostly due to variations in year-class growth. Values from Appendix Table A were then averaged (Table I) to obtain a series of mean lengths to which a curve of growth could be fitted. These lengths are theoretically the same as those obtained at mid year at ages $5\frac{1}{2}$, $6\frac{1}{2}$, etc. The von Bertalanffy growth curve was fitted to the points for ages $5\frac{1}{2}$ to $10\frac{1}{2}$ in the manner outlined by Beverton and Holt (1957, p. 285) giving the equation for growth:

$$l_t = 68.2(1 - e^{-0.28(t-0.91)})$$

where t = age

and l_t = length at age t in centimetres

This equation is applicable to fish of age 5 and over. The curve is plotted in Fig. 2 together with the empirical points for the ages sampled. Ricker (1958, p. 189) has shown that when fast-growing fish are being removed selectively from a fishery each year, a growth rate calculated directly from the size and age of fish at capture may underestimate the true growth rate. In the Lockeport fishery the fast-growing fish in each age-group are removed selectively at least during the sizes when they become vulnerable to the fishing gear (see empirical points 3+ and 4+ in Fig. 2). Thus, the theoretical estimate of growth obtained may be lower than the true value.

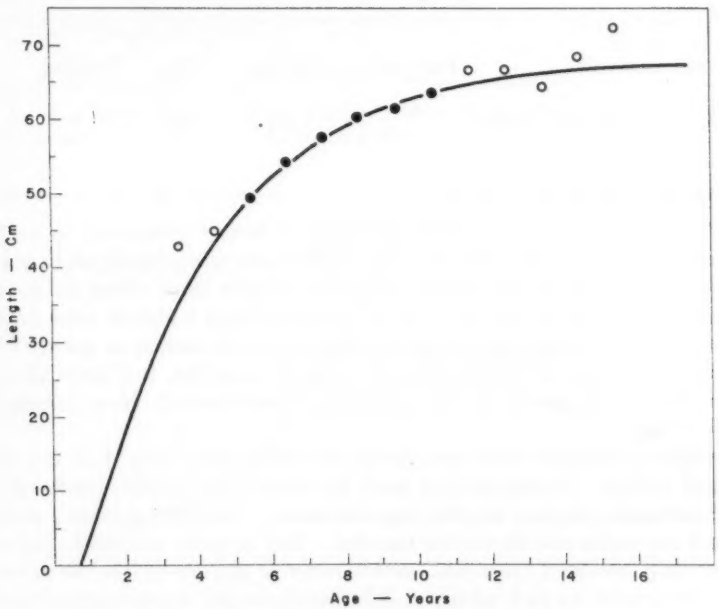

FIG. 2. Growth in length of Lockeport haddock.
Solid dots indicate empirical average lengths used to calculate the theoretical curve.
Open circles indicate empirical average lengths for other ages.

MATURITY AND SPAWNING

Collection and Classification of Data

In 1953 a groundfish bait experiment on the Lockeport grounds provided an opportunity for gross examination of gonads of haddock caught by hook and line. Fish captured were measured and examined. Otoliths were taken from about 20% of them. Dates of sampling and numbers of haddock were:

January 23	(283 fish)
February 24	(171 fish)
March 23	(176 fish)
April 16	(48 fish)
May 1	(48 fish)

The gonads of both males and females were classified according to condition as one of 5 stages: immature, ripening, ripe, running, and spent. The criteria used for the classification were as described in Table I of Homans and Vladykov (1954). However, Stage 2 haddock as described by these authors was recorded in this study as the early indication of the ripening stage (see Table II).

Table II. Comparison of maturity classification of Lockeport haddock to definitions by Homans and Vladykov (1954, p. 536).

Maturity stage of Lockeport haddock	Immature	Ripening	Ripe	Running	Spent
Maturity stage Homans and Vladykov (1954)	1	2 and 3	4	5	6

Age and Length at Maturity

The percentages of immature and mature fish of either sex in each age-group are shown by sexes in Fig. 3. The mature portion included fish in any stage from maturing to spent and all data from the samples listed above for the spring of 1953. The figure shows that the majority of male haddock were immature at 3 years of age and mature at 5 years, the 50% point coming at age 4. For the females, only about 25% were mature when 4 years old, but more than 90% were mature at the age of 5. All members of both sexes in these samples were mature at age 7.

Length-at-maturity data are plotted for these fish in Fig. 4 in the form of smoothed curves. Comparison of data for males and females shows that the former matured at shorter lengths than the latter. The 50% maturity point was at 41 cm for males and 46 cm for females. This is to be expected after noting the age data, provided there was no difference in growth rate between the two sexes. At present we lack adequate information on the separate growth rates of the two sexes, but there is no indication of any great difference from the small amount of data available.

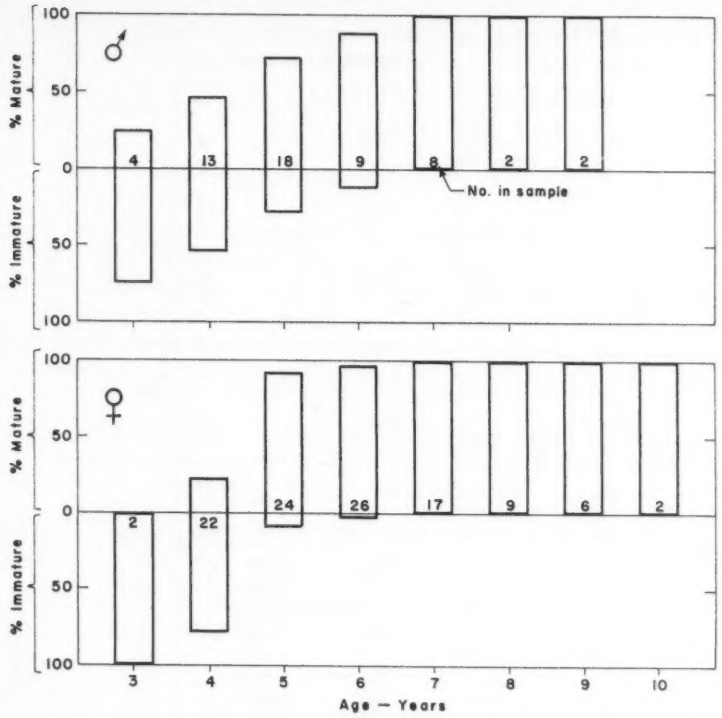

FIG. 3. Age at maturity of the haddock catch from the inshore Lockeport grounds in the spring of 1953.

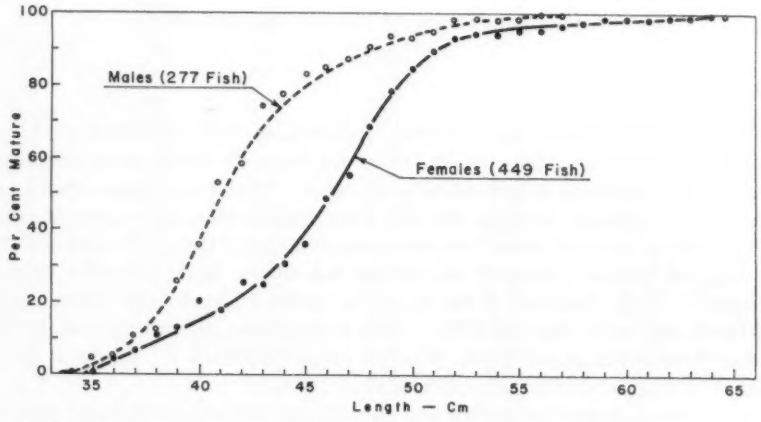

FIG. 4. Length at maturity of the haddock catch from the inshore Lockeport grounds in the spring of 1953 (data smoothed by 5's).

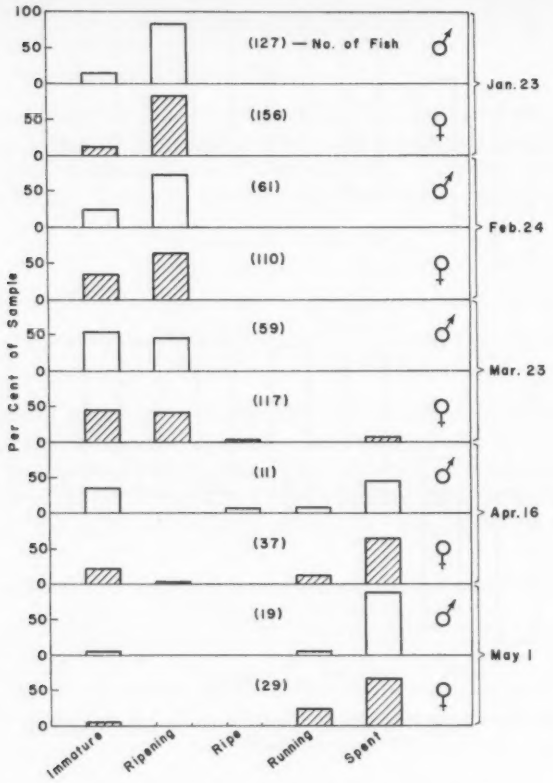

Fig. 5. The haddock spawning period in inshore Lockeport waters, 1953.

Season of Spawning

The spawning period of Lockeport haddock in 1953 is shown in Fig. 5. The five samples were separated by sexes and the individuals were assigned to one of the five maturity stages noted in Table II. The figure shows that in the January and February samples the fish were approaching the spawning stage. In March the presence of some ripe and spent females in the catch indicates that spawning had begun. Most of the mature fish in the April and May samples were spent. Thus, the bulk of the spawning seems to have taken place during late March and early April in 1953. This timing is in general agreement with data for various other northwest Atlantic areas published by Walford (1938), McKenzie (1940), and Homans and Vladykov (1954).

Only a small proportion of ripe and running fish were taken in these samples. There were two reasons for this. These two stages occupy a comparatively short time in the spawning cycle so there is less chance of catching haddock with

gonads at this stage of development. Also, Homans and Vladykov (1954) have shown that a large proportion of these fish cease to feed as the spawning time approaches, thus making them less available to the hook-and-line fishery.

LENGTH–WEIGHT RELATIONSHIP

In the routine samples only the lengths of haddock were measured. A series of special samples was taken in order that the length measurements might be converted to weights. In these samples lengths were recorded in centimetres and eviscerated weights in pounds and ounces for individual fish. For ease in calculations, ounces were converted to decimal fractions of pounds in this study. As the fish were gutted and gilled before measurement, the variations in weight

TABLE III. Data used in calculating the length–weight relation for Lockeport haddock.

Length	Eviscerated weight			Average weight for year	Values calculated from equation	No. of fish examined
	Feb.–May	June–Sept.	Oct.–Jan.			
cm	*lb*	*lb*	*lb*	*lb*	*lb*	
36	0.92	0.88	0.95	0.92	0.94	11
37	1.00	0.96	1.00	0.99	1.02	7
38	1.11	1.05	1.08	1.08	1.10	18
39	1.21	1.15	1.18	1.18	1.19	24
40	1.28	1.29	1.35	1.31	1.28	18
41	1.37	1.32	1.38	1.36	1.38	38
42	1.48	1.45	1.52	1.48	1.48	53
43	1.63	1.59	1.62	1.61	1.59	52
44	1.69	1.68	1.78	1.72	1.70	63
45	1.79	1.82	1.90	1.84	1.82	63
46	1.92	1.94	2.02	1.96	1.95	83
47	2.08	2.14	2.16	2.13	2.07	79
48	2.26	2.25	2.38	2.30	2.21	65
49	2.27	2.31	2.48	2.35	2.35	80
50	2.47	2.52	2.62	2.54	2.50	78
51	2.59	2.70	2.80	2.70	2.65	82
52	2.65	2.78	2.95	2.79	2.80	89
53	2.89	3.03	3.18	3.03	2.97	72
54	3.12	3.13	3.32	3.19	3.14	55
55	3.20	3.21	3.50	3.30	3.30	45
56	3.51	3.45	3.52	3.49	3.50	44
57	3.33	3.42	3.85	3.53	3.69	42
58	3.50	3.71	4.09	3.77	3.88	35
59	3.82	4.12	4.27	4.07	4.09	36
60	4.00	4.59	4.55	4.38	4.30	16
61	4.51	4.38	4.77	4.55	4.52	23
62	4.46	4.47	5.06	4.66	4.74	26
63	4.50	4.88	5.38	4.92	4.97	18
64	4.50	5.14	5.92	5.19	5.21	18
65	5.11	5.25	5.69	5.35	5.46	11
66	5.00	5.56	6.69	5.75	5.71	13
67	5.44	6.03	6.32	5.93	5.97	11
					Total	1368

of the sexual organs and variations due to amounts of food in the stomach were eliminated. However, differences in average weight of eviscerated fish at any chosen length were noticeable at different times of the year.

The differences in mature fish were probably related to variations in intensity of feeding in haddock, such as have been demonstrated by Homans and Vladykov (1954). They found that haddock feed heavily during June to October and relatively lightly from November to May. They also stated that during the months of February to May only a very small percentage of the haddock continued to feed. To examine the effect of these feeding habits on gutted weight of fish, our data have been broken down into three time periods, February to May, June to September, and October to January (Table III). In the Table the majority of the mature fish are seen to be lightest in February to May, of medium weight from June to September, and heaviest from October to January for any

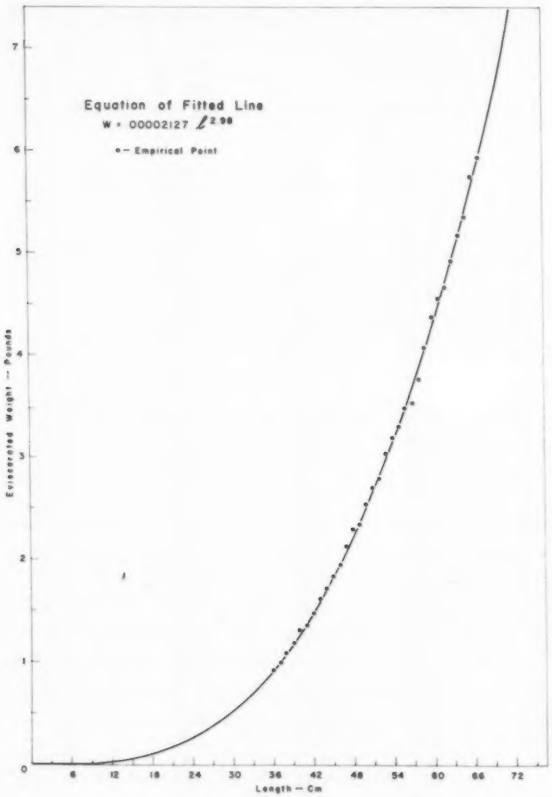

FIG. 6. The length–weight relationship for inshore Lockeport haddock.

one length group above the 50% maturity point of 46 cm (females) already demonstrated for these fish.

These changes in weights are related to our spawning data and those from Homans and Vladykov in that during the period of spawning and cessation of feeding (February to May) the gutted specimens were lightest. They were regaining weight from June to September when spawning was over and the fish were feeding heavily, and they reached their best condition in October to January just prior to the next spawning season.

In order to obtain an average relationship of length to weight for Lockeport haddock, data for the three above-mentioned periods were combined to give mean values for the year (Table III). To these data a length–weight equation of the type

$$W = al^k$$

was fitted to give the values:

$$W = 0.00002127l^{2.98}$$

where W = weight in pounds, gutted and gilled

and l = length in centimetres

This theoretical curve is shown in Fig. 6 and data from it were used for calculations of growth in weight.

GROWTH IN WEIGHT

By using growth-in-length data and the length–weight relationship, it was possible to arrive at an equation for growth in weight, the form most useful in assessments of yield of the fishery. The calculation of mean weights of age-groups was carried out in a manner suggested by Ricker (1958) who cautioned that "the

TABLE IV. Mean weights in pounds of haddock age-groups sampled from landings of inshore Lockeport catches from 1946 to 1954.

Sampling quarter		Age					
		5	6	7	8	9	10
Feb.–Apr.	n	190.76	130.29	53.99	22.33	6.53	7.95
	$\bar{x}$	2.34	3.01	3.92	4.15	4.63	5.45
May–July	n	97.60	37.22	30.96	17.16	16.56	10.32
	$\bar{x}$	2.51	3.27	4.05	4.18	4.62	5.16
Aug.–Oct.	n	96.32	92.18	39.67	33.80	24.07	5.08
	$\bar{x}$	2.33	3.17	3.90	4.65	4.76	5.27
Nov.–Jan.	n	297.08	169.65	124.26	43.92	32.34	16.17
	$\bar{x}$	2.78	3.51	3.90	4.54	5.15	5.11
Average weight for year		2.49	3.24	3.94	4.38	4.79	5.25

weight of a fish whose length is exactly l is less than the average weight of a series of fish of varying sizes whose average length is l''. Accordingly, lengths were converted to weights in Appendix Table A and frequencies were multiplied by weights to get average weights of age-groups. In this case, average weights arrived at by this method were only very slightly higher (average 0.05 lb) than those which could be obtained by direct conversion of mean lengths. Again, for calculation of the Bertalanffy equation, averages over the years for ages 5 to 10 were used (Table IV). The data were fitted according to the manner described in Beverton and Holt (1957, pp. 282–285). The curve for the equation (in pounds, gutted and gilled)

$$W_t = 6.46(1 - e^{-0.27(t-0.70)})^{2.98}$$

is shown in Fig. 7.

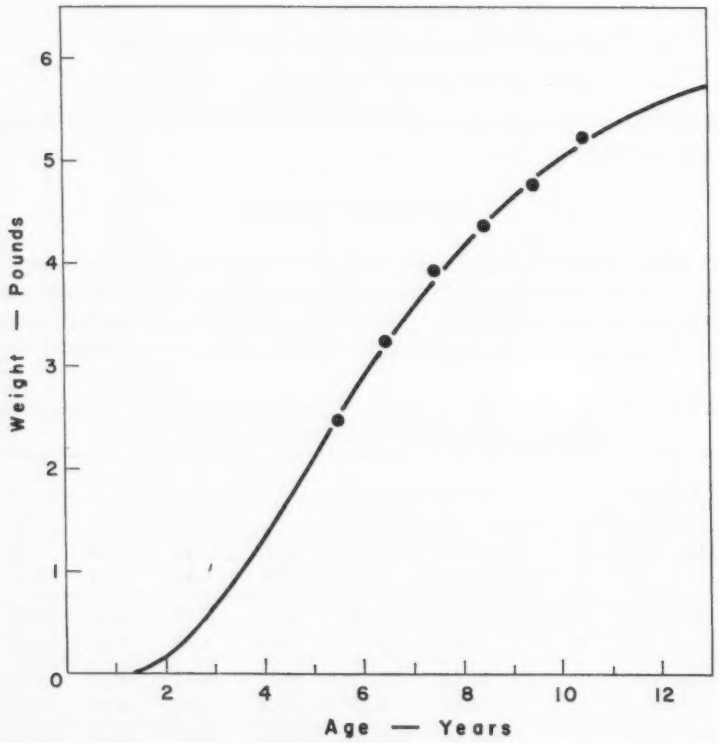

FIG. 7. Growth in eviscerated weight of Lockeport haddock. The curve is fitted to weight points which were computed by converting empirical average lengths to weights using the length–weight relation shown in Fig. 6. Solid dots indicate weights used.

GROWTH CHANGES AT LOCKEPORT

Needler (1929) published growth information for inshore Lockeport haddock calculated from scale samples and lengths collected in 1926. Part of these growth data (ages 5 to 13) are reproduced in Fig. 8 together with the average

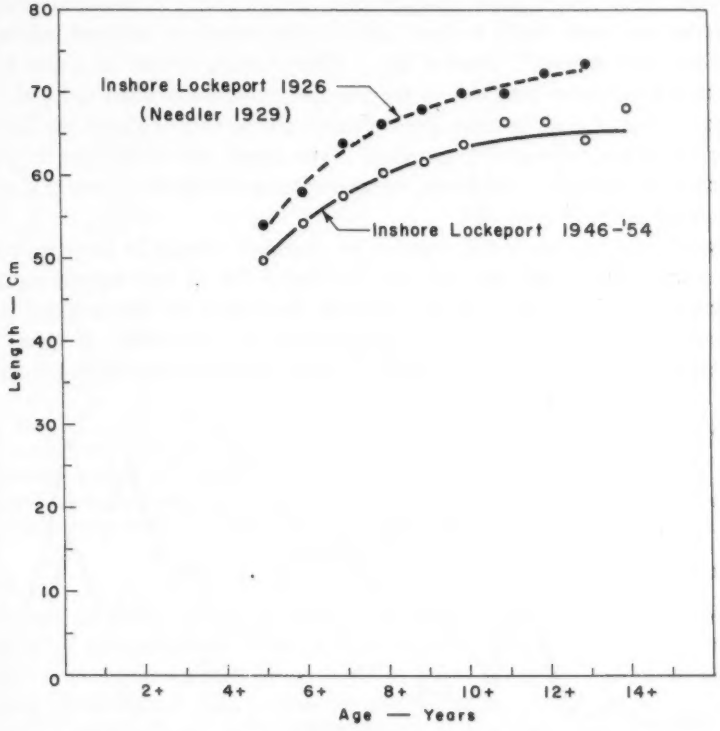

FIG. 8. Growth curves for inshore Lockeport haddock (summer). Empirical points and theoretical curves are shown.

growth curve for haddock from the same area for 1946 to 1954 (from Fig. 2). The two curves are comparable in that Needler's data were collected from June 15 to August 15, while data for the 1946–54 curve were averaged from the four quarterly summaries (Table I). However, for comparative purposes the 1946–54 averages could be slightly high as we have found indications of growth in all quarters of the year (Fig. 1), while Needler believed that most of the growth at that time took place between August 15 and October 15.

Comparison of mean lengths at equivalent ages in Fig. 8 shows a 5 cm difference at age 5 increasing to about 7 cm at age 13, the 1926 growth line being the higher. The estimated rate of growth of haddock in the area has changed

considerably in the approximately 25-year interval separating the two studies. Investigation of the causes of the difference has shown that we cannot attribute it to any one particular cause, but rather to a combination of factors. First of all, the difference in age-determination methods was considered. The relative usefulness of haddock scales and otoliths as age-determination tools has been the subject of an earlier paper (Kohler and Clark, 1958). It was found that the age reader was more likely to lose sight of edge annuli in haddock scales than in otoliths for fish over 7 years of age. This "reading down" in scales has the effect of placing more long fish in the younger age-groups when using the scale method. Thus, a growth curve from scales could be shifted above the curve for similar specimens from otolith readings. The upper part of Needler's curve in Fig. 8 may be affected in this way, especially since the spread between scale and otolith lines increases with age.

Another factor that could produce an apparent change in growth rate is a major increase in fishing mortality for the longer fish of each age-group during recruitment. This would have the effect of depressing the mean length of the age-groups even after recruitment, throughout the remainder of their lives. That this sort of effect may have occurred is shown by examining Shelburne County

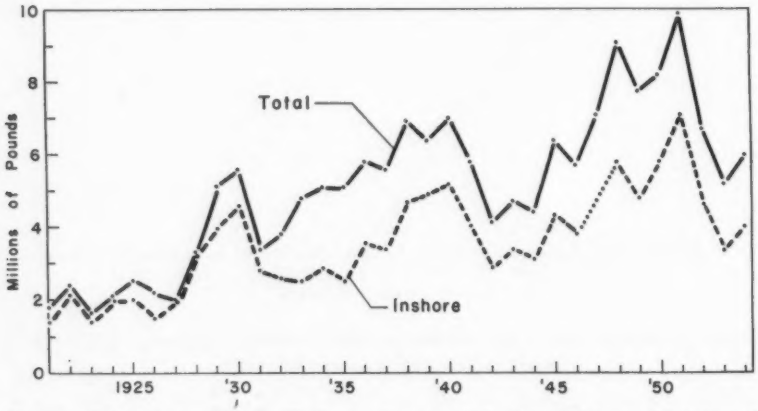

FIG. 9. Haddock landings in Shelburne County, N.S. (from Fisheries Statistics of Canada publications and some detailed information from Dominion Bureau of Statistics field data).

haddock landings for the years 1921 to 1954 (Fig. 9). The inshore landings shown in the Figure can be taken as a specific indication of the increase in landings from the Lockeport haddock population by Canadians, while the line for total landings includes some offshore fish. The Figure shows that the post-1926 inshore haddock landings have averaged roughly twice that of the pre-1926 values.

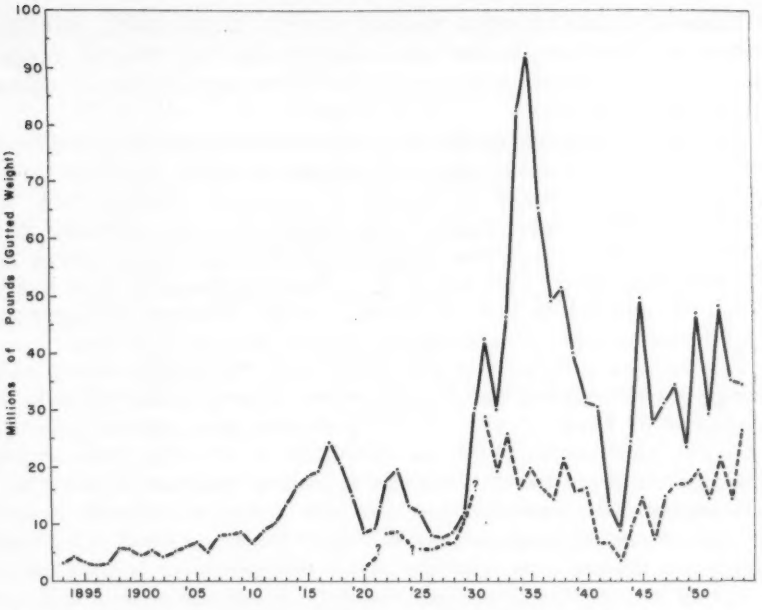

FIG. 10. United States haddock landings from ICNAF Subarea 4. The solid line indicates total United States landings from Subarea 4 (data from ICNAF statistics). The broken line indicates landings at certain important New England ports from United States statistical areas XXI N, O, and P (from Fisheries Statistics of United States).

Figure 10 shows the extent of United States fishing operations in the area. Landings of haddock from Subarea 4 of the International Commission for the Northwest Atlantic Fisheries from 1893 to 1954 reflect the increased removals from the Nova Scotian area in general over the years. Landings from Roseway, LaHave, Little LaHave, and Browns Banks (U.S. statistical areas XXI N, O, and P) are also shown. Tagging experiments (McCracken, 1956) have shown that haddock in these areas mix with and are part of the inshore Lockeport population. United States landings shown for these areas (although from statistics gathered only at certain important New England ports, and not always the same ports: see Fisheries Statistics of the United States, 1921–1954), reflect an upward trend similar to those of United States Subarea 4 landings as a whole and to the Canadian Shelburne County landings.

Most of the United States catch in these offshore areas has been made by otter trawlers which presumably used nets with a codend mesh size of $2\frac{7}{8}$ inches (Graham, 1952) during the period under consideration. According to Graham, this type of gear retained almost all haddock over 30 cm in length, and those not commercially useful were discarded dead at sea. This brings fishing mortality into the picture at a younger age than with the Canadian line fishery.

These increases in haddock landings and the smaller size at first capture during more recent years in the area under investigation reflect an increase in fishing mortality. As mentioned earlier, this has the resultant effect of depressing the 1946–54 growth curve.

Other factors investigated that could affect estimated growth curves included line fishing gear selection and catch cull, temperature effects, and density effects. A check of Needler's length distribution of age-groups (Needler, 1929, fig. 5) against the 1946–54 data (Appendix A) showed that any difference in gear selection or catch cull on similar length distributions for the two periods might have shifted the mean length for age 5. However this would have had little influence on older fish because the majority of the older ones had grown past any such selection and cull range known to have operated in the area.

In some cases a change in growth of fish in an area has been associated with a change in environmental temperatures, a rise in temperature generally being accompanied by faster growth. However, in this case, apparent growth has become less, while Lauzier (1954) has shown that water temperatures in general in the region have increased. In a similar manner, decreases in stock density usually should make more food available with a resultant increase in growth rate. In this case, although decrease in density could be a result of increases in landings over the years, the apparent growth of haddock has become less.

Taking into account the probability of the interaction of several factors in producing an apparent change in growth, the most obvious possibilities were differences in age-determination methods and variation in fishing mortality at recruitment. Environmental factors other than those discussed have not in this case been measured in sufficient detail in this area during the two periods to permit valid comparisons.

SUMMARY

1. Age-length data collected from haddock caught in the Lockeport, N.S. area between 1946 and 1954 have been combined to give a Bertalanffy-type growth curve. The equation of the curve which applies to fish of age 5 and over is:

$$l_t = 68.2(1 - e^{-0.28(t-0.91)})$$

where t = age in years

and l_t = length at age t in centimetres

2. Data collected in 1953 indicate that 50% of the male haddock were mature at 4 years of age and 41 cm. The equivalent 50% point for females fell between 4 and 5 years of age and 46 cm.

3. During 1953 most of the haddock in the area spawned in late March and early April.

4. An analysis of length–weight data showed that the mature, eviscerated fish at lengths above 46 cm had low, intermediate, and high weights in the periods February to May, June to September, and October to January,

respectively. These changes were shown to be related to spawning and feeding activities. The average length–weight equation derived from the combined data was:

$$W = 0.00002127l^{2.98}$$

where W = weight in pounds, gutted and gilled
and l = length in centimetres

5. The conversion equation from length to weight was used to change age–length to age–weight data. An age–weight curve was then fitted to the data to reduce them to the form most useful for yield calculations. The equation of this curve was:

$$W_t = 6.46(1 - e^{-0.27(t-0.70)})^{2.98}$$

where W_t = weight in pounds, gutted and gilled at age t
and t = age in years

6. Differences in the apparent growth pattern of these haddock between the 1926 and the 1946–54 period were not easily attributed to any one factor. Investigation of various possibilities indicated that differences in methods of age determination and variation in fishing mortality at recruitment could account for at least part of the change. Other unmeasured environmental factors may have been partially responsible.

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I wish to express my appreciation for criticism of the text given by Dr W. R. Martin and Dr F. D. McCracken. Most of the field data were collected under Dr Martin's supervision by Mr D. N. Fitzgerald.

My thanks are also due to Dr M. J. Dunbar who guided the work during its preparation for thesis purposes.

REFERENCES

ANON. 1921–1954. Fisheries Statistics of United States. U.S. Fish and Wildlife Service.

BEVERTON, R. J. H. AND S. J. HOLT. 1957. On the dynamics of exploited fish populations. *U.K. Min. of Agric., Fish. and Food, Fish. Invest.*, Ser. 2, **19**, 533 pp.

HOMANS, R. E. S. AND V. D. VLADYKOV. 1954. Relation between feeding and the sexual cycle of haddock. *J. Fish. Res. Bd. Canada*, **11**(5): 535–542.

GRAHAM, H. W. 1952. Mesh regulation to increase the yield of the Georges Bank haddock fishery. *Second Ann. Rept. Internat. Comm. for the Northwest Atlantic Fish.*, Part 3, pp. 23–33.

KOHLER, A. C. 1958. The validity of otolith age determinations for haddock (*Melanogrammus aeglefinus* L.) from the Lockeport, N. S. area. *J. Fish. Res. Bd. Canada*, **15**(6): 1229–1238.

KOHLER, A. C. AND J. R. CLARK. 1958. Haddock scale-otolith comparisons. *J. Fish. Res. Bd. Canada*, **15**(6): 1239–1246.

LAUZIER, L. 1954. Recent surface water temperatures along the Canadian Atlantic coast. Cold years—warm years. *Fish. Res. Bd. Canada, Atlantic Prog. Rept.*, No. 58, pp. 6–11.

MCCRACKEN, F. D. 1956. Cod and haddock tagging off Lockeport, N.S. *Fish. Res. Bd. Canada, Atlantic Prog. Rept.*, No. 64, pp. 10–15.

MCCRACKEN, F. D. MS 1957. Hook selection for cod and haddock. Paper S.9 presented to Joint Scientific Meeting of ICNAF, ICES, and FAO, Lisbon, Portugal.

MCKENZIE, R. A. 1940. Spring haddock "run", Jordan Harbour, N.S. *Fish. Res. Bd. Canada, Atlantic Prog. Rept.*, No. 28, pp. 9–13.

NEEDLER, A. W. H. 1929. Studies on the life-history of the haddock (*Melanogrammus aeglefinus* Linnaeus). *Contrib. Canadian Biol. and Fish.*, N.S., **4**(20): 267–285.

RICKER, W. E. 1958. Handbook of computations for biological statistics of fish populations. *Bull. Fish. Res. Bd. Canada*, No. 119, 299 pp.

WALFORD, L. A. 1938. Effect of currents on distribution and survival of the eggs and larvae of the haddock (*Melanogrammus aeglefinus*) on Georges Bank. *Bull. U.S. Bur. Fish.*, **49**(29), 73 pp.

WISE, J. P. 1958. Growth rate of Browns Bank haddock. *U.S. Fish and Wildlife Service, Research Rept.*, No. 50.

APPENDIX TABLE A(1). Age, length and weight frequencies of haddock samples taken in the February to April period from the inshore Lockeport grounds.

Theoretical weight	Length	Age in years												
		3	4	5	6	7	8	9	10	11	12	13	14	15
lb	*cm*													
8.70	76	...	...	...	...	...	...	...	...	...	...	...	...	...
8.36	75	...	...	...	...	...	...	...	0.91	...	...	...	...	...
8.04	74	...	...	...	...	...	...	...	...	...	...	...	...	1.00
7.72	73	...	...	...	...	...	...	...	...	...	...	...	1.00	0.98
7.41	72	...	...	...	...	...	...	...	...	...	0.91	...	1.00	...
7.10	71	...	...	...	...	...	...	...	...	...	...	...	...	1.02
6.81	70	...	...	...	...	...	...	...	...	...	0.98	...	1.00	...
6.52	69	...	...	...	...	...	...	...	...	...	...	...	...	...
6.24	68	...	...	...	...	0.91	...	...	1.11	0.91	1.02	...	1.93	...
5.97	67	...	...	...	...	...	1.02	0.98	1.00	...	0.98	0.96	...	...
5.71	66	...	...	1.00	...	1.00	1.82	1.91	...	...	...	...	...	...
5.46	65	...	...	...	...	1.00	1.02	...	1.00	1.04	...	...	1.00	...
5.21	64	...	...	...	0.98	2.00	...	...	...	1.00	...	...	...	...
4.97	63	...	...	...	...	3.93	0.91	0.91	1.02	0.91	...	1.02	...	...
4.74	62	...	...	...	2.80	2.91	2.93	...	...	...	...	...	...	...
4.52	61	...	...	0.91	4.04	2.89	4.89	...	0.98	0.98	1.00	1.00	...	...
4.30	60	...	...	1.13	5.75	2.91	0.96	...	...	...	...	...	...	...
4.09	59	...	...	...	2.82	7.02	1.98	...	1.93	0.91	...	...	...	0.94
3.88	58	...	...	4.00	3.99	4.82	1.87	0.91	...	...	...	...	...	...
3.69	57	...	...	0.93	7.65	3.89	0.96	...	...	...	...	...	...	...
3.50	56	...	...	2.94	9.76	3.98	1.93	...	...	...	...	...	...	...
3.32	55	...	...	3.86	5.96	3.90	1.02	...	...	...	...	...	...	...
3.14	54	...	1.13	9.15	11.64	3.73	...	0.91	...	...	...	...	...	...
2.97	53	...	0.91	6.31	13.03	2.93	...	...	...	...	...	...	...	...
2.80	52	...	0.94	16.13	14.51	3.04	1.02	0.91	...	...	...	...	...	...
2.65	51	...	1.04	11.39	9.00	2.02	...	...	...	...	...	...	...	...
2.50	50	...	4.02	17.80	7.64	...	...	...	...	...	...	...	...	...
2.35	49	...	4.01	10.72	6.35	1.11	...	...	...	...	...	...	...	...
2.21	48	...	5.76	22.76	6.21	...	...	...	...	...	...	...	...	...
2.07	47	...	4.81	21.99	6.35	...	...	...	...	...	...	...	...	...
1.95	46	...	8.08	12.33	3.15	...	...	...	...	...	...	...	...	...
1.82	45	...	3.15	19.01	5.64	...	...	...	...	...	...	...	...	...
1.70	44	...	12.23	9.07	1.06	...	...	...	...	...	...	...	...	...
1.59	43	0.92	15.20	8.48	1.04	...	...	...	...	...	...	...	...	...
1.48	42	...	12.30	3.82	0.92	...	...	...	...	...	...	...	...	...
1.38	41	1.06	11.56	2.96	...	...	...	...	...	...	...	...	...	...
1.28	40	...	12.36	2.03	...	...	...	...	...	...	...	...	...	...
1.19	39	1.99	5.15	1.04	...	...	...	...	...	...	...	...	...	...
1.10	38	...	3.93	1.00	...	...	...	...	...	...	...	...	...	...
1.02	37	...	1.85	...	...	...	...	...	...	...	...	...	...	...
0.94	36	...	5.64	...	...	...	...	...	...	...	...	...	...	...
0.86	35	...	1.02	...	...	...	...	...	...	...	...	...	...	...
No. of fish	n		115.09	190.76	130.29	53.99	22.33	6.53	7.95	5.75	4.89	2.98	5.93	3.94
Mean length cm	$\bar{x}$		43.09	48.59	52.86	57.88	60.32	60.99	64.61	63.35	67.51	63.62	69.35	69.40
Standard deviation	$S_{\bar{x}}$		0.36	0.32	0.40	0.57	0.80	2.36	1.87	1.29	1.88	1.76	1.22	3.45
Average weight lb				2.34	3.01	3.92	4.15	4.63	5.45					

APPENDIX TABLE A(2). Age, length and weight frequencies of haddock samples taken in the May to July period from the inshore Lockeport grounds.

Theoretical weight	Length	Age in years												
lb	*cm*	3	4	5	6	7	8	9	10	11	12	13	14	15
9.05	77	...	...	...	...	...	...	...	...	0.88	...	...	...	...
8.70	76	...	...	...	...	...	...	...	...	...	...	...	...	...
8.36	75	...	...	...	...	...	...	...	...	...	...	...	...	...
8.04	74	...	...	...	...	1.34	...	...	1.00	...	...	...	...	...
7.72	73	...	...	...	...	...	...	...	...	1.00	...	...	...	...
7.41	72	...	...	...	...	...	...	...	...	...	...	...	...	...
7.10	71	...	...	...	...	...	...	...	...	1.00	...	...	...	...
6.81	70	...	...	...	...	...	...	1.00	1.00	1.00	...	...	...	...
6.52	69	...	...	...	...	...	...	...	...	...	...	...	...	...
6.24	68	...	...	...	...	...	1.00	...	...	...	...	...	...	...
5.97	67	...	...	...	...	...	...	...	...	...	...	...	...	...
5.71	66	...	...	...	1.00	...	0.88	1.34	0.88	...	...	...	...	...
5.46	65	...	...	...	...	...	1.00	1.00	...	...	0.88	1.00	...	...
5.21	64	...	...	...	1.88	...	...	...	1.00	...	...	1.34	...	...
4.97	63	...	...	1.00	...	3.76	0.88	2.34	1.34	0.88	2.34	...	...	...
4.74	62	...	...	...	1.34	...	1.76	1.88	...	...	...	1.00	...	...
4.52	61	...	...	1.00	1.00	4.34	...	4.00	1.88	...	...	...	...	...
4.30	60	...	...	1.00	...	2.00	...	...	2.22	...	...	...	...	...
4.09	59	...	...	1.00	1.00	...	2.64	...	...	...	...	...	...	...
3.88	58	...	...	...	1.00	4.00	4.00	2.00	...	...	...	...	...	...
3.69	57	...	...	4.56	2.00	4.76	1.00	1.00	...	...	...	...	...	...
3.50	56	...	...	2.00	4.00	5.00	1.00	1.00	1.00	...	...	...	...	...
3.32	55	...	...	3.34	2.00	0.88	...	...	...	...	...	...	...	...
3.14	54	...	1.00	1.00	3.00	3.00	...	...	...	...	...	...	...	...
2.97	53	...	...	6.10	6.00	...	2.00	1.00	...	...	...	...	...	...
2.80	52	...	...	5.24	4.00	1.00	1.00	...	...	...	...	...	...	...
2.65	51	0.88	1.00	14.78	3.00	...	...	...	...	...	...	...	...	...
2.50	50	...	1.00	8.32	...	...	...	...	...	...	...	...	...	...
2.35	49	...	1.00	7.64	2.00	0.88	...	...	...	...	...	...	...	...
2.21	48	...	2.04	9.92	1.00	...	...	...	...	...	...	...	...	...
2.07	47	...	...	9.32	2.00	...	...	...	...	...	...	...	...	...
1.95	46	...	1.00	2.36	1.00	...	...	...	...	...	...	...	...	...
1.82	45	...	1.00	7.68	...	...	...	...	...	...	...	...	...	...
1.70	44	...	1.04	6.68	...	...	...	...	...	...	...	...	...	...
1.59	43	...	3.34	3.00	...	...	...	...	...	...	...	...	...	...
1.48	42	2.00	3.66	0.66	...	...	...	...	...	...	...	...	...	...
1.38	41	...	...	...	...	...	...	...	...	...	...	...	...	...
1.28	40	...	2.70	1.00	...	...	...	...	...	...	...	...	...	...
1.19	39	...	1.00	...	...	...	...	...	...	...	...	...	...	...
1.10	38	...	...	...	...	...	...	...	...	...	...	...	...	...
1.02	37	...	...	...	...	...	...	...	...	...	...	...	...	...
0.94	36	...	1.00	...	...	...	...	...	...	...	...	...	...	...
0.86	35	...	...	...	...	...	...	...	...	...	...	...	...	...
No. of fish	n		20.78	97.60	37.22	30.96	17.16	16.56	10.32	4.76	3.22	3.34		
Mean length cm	$\bar{x}$		44.25	49.71	54.34	58.45	59.11	61.20	63.41	70.84	63.55	63.70		
Standard deviation	$S_{\bar{x}}$		0.98	0.63	0.88	0.85	1.35	1.44	2.11	2.28	0.60	0.79		
Average weight lb				2.51	3.27	4.05	4.18	4.62	5.16					

APPENDIX TABLE A(3). Age, length and weight frequencies of haddock samples taken in the August to October period from the inshore Lockeport grounds.

Theoretical weight	Length	Age in years												
		3	4	5	6	7	8	9	10	11	12	13	14	15
lb	*cm*													
12.61	84	...	...	...	...	...	...	...	...	...	...	...	...	1.03
8.04	74	...	...	...	...	...	...	...	...	1.00	...	...	...	0.98
7.72	73	...	...	...	...	...	...	...	...	...	...	...	...	...
7.41	72	...	...	...	...	...	...	...	...	0.94	...	...	...	...
7.10	71	...	...	...	...	...	...	...	...	...	...	...	...	...
6.81	70	...	...	...	...	...	1.14	...	...	1.00	...	...	...	...
6.52	69	...	...	...	...	...	...	...	2.00	...	...	...	1.00	0.93
6.24	68	...	...	...	...	1.14	1.00	1.14	...	...	...	...	...	...
5.97	67	...	...	...	...	1.14	2.92	2.03	...	0.94	1.00	1.14	...	...
5.71	66	...	...	...	...	2.16	1.03	...	...	...	...	...	1.00	...
5.46	65	...	...	...	2.16	1.16	...	3.16	...	...	...	...	...	...
5.21	64	...	...	...	...	1.03	2.00	1.14	...	0.94	1.16	...	...	...
4.97	63	...	...	...	2.14	1.16	2.06	3.32	...	...	...	...	...	...
4.74	62	...	...	...	1.00	...	6.28	3.17	1.16	...	...	...	...	...
4.52	61	...	...	...	1.00	2.03	5.33	2.10	...	...	...	...	...	...
4.30	60	...	...	...	5.22	2.14	1.96	1.92	1.92	...	...	...	...	...
4.09	59	...	...	...	3.98	4.93	3.16	0.93	...	...	...	...	...	...
3.88	58	...	1.14	...	4.10	3.81	0.98	2.10	...	...	...	0.94	...	...
3.69	57	...	...	1.00	3.28	1.92	2.03	1.00	...	...	...	...	...	...
3.50	56	1.16	1.03	0.98	7.86	2.01	2.00	2.06	...	...	...	...	...	...
3.32	55	1.16	1.14	1.93	8.74	3.12	...	...	...	...	...	...	...	...
3.14	54	...	1.92	5.30	6.66	3.96	0.93	...	...	...	...	...	...	...
2.97	53	1.16	3.14	3.69	7.68	2.96	...	...	...	...	...	...	...	...
2.80	52	...	...	5.06	4.82	2.00	0.98	...	...	...	...	...	...	...
2.65	51	...	4.19	9.98	13.84	...	...	...	...	...	...	...	...	...
2.50	50	...	2.32	12.47	3.94	...	...	...	...	...	...	...	...	...
2.35	49	2.32	4.19	7.55	7.80	...	...	...	...	...	...	...	...	...
2.21	48	3.32	8.03	8.68	1.85	2.00	...	...	...	...	...	...	...	...
2.07	47	...	8.92	14.35	2.02	1.00	...	...	...	...	...	...	...	...
1.95	46	...	7.97	5.71	0.98	...	...	...	...	...	...	...	...	...
1.82	45	0.71	6.46	8.77	0.92	...	...	...	...	...	...	...	...	...
1.70	44	0.88	8.14	6.38	0.98	...	...	...	...	...	...	...	...	...
1.59	43	...	8.41	3.36	...	...	...	...	...	...	...	...	...	...
1.48	42	1.73	7.29	1.11	1.21	...	...	...	...	...	...	...	...	...
1.38	41	2.81	6.93	...	...	...	...	...	...	...	...	...	...	...
1.28	40	0.88	5.43	...	...	...	...	...	...	...	...	...	...	...
1.19	39	1.59	3.18	...	...	...	...	...	...	...	...	...	...	...
1.10	38	...	1.11	...	...	...	...	...	...	...	...	...	...	...
1.02	37	...	...	...	...	...	...	...	...	...	...	...	...	...
0.94	36	3.63	1.23	...	...	...	...	...	...	...	...	...	...	...
0.86	35	...	...	...	...	...	...	...	...	...	...	...	...	...
No. of fish	n		92.17	96.32	92.18	39.67	33.80	24.07	5.08	4.82	2.16	2.08	2.00	2.94
Mean length cm	$\bar{x}$		45.47	48.65	53.79	57.63	61.34	61.90	64.00	69.46	65.39	62.93	67.50	75.92
Standard deviation	$S_{\bar{x}}$		0.46	0.33	0.48	0.83	0.69	0.71	2.03	1.81	1.39	4.31	1.50	4.50
Average weight lb				2.33	3.17	3.90	4.65	4.76	5.27					

APPENDIX TABLE A(4). Age, length and weight frequencies of haddock samples taken in the November to January period from the inshore Lockeport grounds.

Theoretical weight	Length	Age in years												
lb	*cm*	3	4	5	6	7	8	9	10	11	12	13	14	15
8.70	76	...	...	...	...	...	...	...	...	...	1.03	...	...	...
8.36	75	...	...	1.07	...	...	...	...	...	...	...	...	...	...
8.04	74	...	...	...	...	...	...	...	...	1.00	...	...	...	...
7.72	73	...	...	...	...	...	...	1.97	...	...	1.00	...	...	...
7.41	72	...	1.07	...	...	...	...	...	...	...	...	...	...	...
7.10	71	...	...	...	1.02	...	...	...	...	1.00	1.00	...	...	...
6.81	70	...	...	...	...	...	1.13	1.00	1.00	2.07	1.04	...	...	...
6.52	69	...	...	...	...	...	...	3.00	...	1.00	...	...	...	...
6.24	68	...	1.07	...	1.07	1.00	2.36	3.98	1.03	...	...	1.00	...	...
5.97	67	...	...	...	0.68	1.11	1.00	1.02	1.00	0.95	...	1.00	...	...
5.71	66	...	1.07	...	2.00	2.05	1.09	2.02	...	3.00	1.00	...	...	...
5.46	65	...	...	...	1.00	6.49	2.13	1.00	3.13	1.00	1.00	...	...	...
5.21	64	...	...	1.07	5.95	7.90	3.09	...	2.00	1.00	...	...	...	...
4.97	63	...	...	1.00	6.03	3.00	2.11	2.03	3.88	1.05	...	...	...	...
4.74	62	...	...	...	4.21	1.98	6.00	4.00	1.13	2.00	...	...	...	...
4.52	61	...	1.07	2.99	6.85	5.09	5.99	2.13	...	1.07	...	...	...	...
4.30	60	...	...	4.23	5.68	6.63	4.22	1.00	1.00	0.95	...	...	...	...
4.09	59	...	3.05	6.60	11.99	15.98	5.24	3.00	...	...	...	...	...	...
3.88	58	2.00	1.07	6.28	13.78	13.30	3.26	...	...	...	...	...	...	...
3.69	57	...	...	11.55	10.97	8.16	...	3.04	...	...	...	...	...	...
3.50	56	...	2.01	11.32	9.85	14.81	1.11	1.13	2.00	1.07	...	...	...	...
3.32	55	...	2.70	21.37	9.09	8.98	...	2.02	...	...	...	...	...	...
3.14	54	...	4.26	30.87	14.00	7.62	1.11	...	...	...	...	...	...	...
2.97	53	1.09	12.16	21.31	16.40	4.12	...	...	...	...	...	...	...	...
2.80	52	1.00	13.72	28.97	16.90	7.02	3.08	...	...	...	...	...	...	...
2.65	51	1.05	20.40	23.50	9.25	5.03	1.00	...	...	1.07	...	...	...	...
2.50	50	2.52	15.33	24.66	8.90	1.05	...	...	...	1.07	...	...	...	...
2.35	49	2.70	13.32	25.13	4.11	1.99	...	...	...	...	...	...	...	...
2.21	48	6.17	20.88	19.93	2.12	...	...	...	...	...	...	...	...	...
2.07	47	9.80	19.30	17.82	4.04	...	...	...	...	...	...	...	...	...
1.95	46	7.09	26.34	14.06	0.86	0.95	...	...	...	...	...	...	...	...
1.82	45	8.94	20.02	7.74	1.88	...	...	...	...	...	...	...	...	...
1.70	44	11.30	14.60	3.90	1.02	...	...	...	...	...	...	...	...	...
1.59	43	10.65	21.29	7.55	...	...	...	...	...	...	...	...	...	...
1.48	42	7.81	6.10	2.12	...	...	...	...	...	...	...	...	...	...
1.38	41	7.81	6.10	1.02	...	...	...	...	...	...	...	...	...	...
1.28	40	13.87	5.32	1.02	...	...	...	...	...	...	...	...	...	...
1.19	39	8.58	5.20	...	...	...	...	...	...	...	...	...	...	...
1.10	38	3.40	5.81	...	...	...	...	...	...	...	...	...	...	...
1.02	37	5.76	2.83	...	...	...	...	...	...	...	...	...	...	...
0.94	36	7.26	1.12	...	...	...	...	...	...	...	...	...	...	...
0.86	35	1.52	...	...	...	...	...	...	...	...	...	...	...	...
No. of fish	n	122.79	251.72	297.08	169.65	124.26	43.92	32.34	16.17	19.30	6.07	2.00		
Mean length cm	$\bar{x}$	43.0	47.2	51.5	55.6	57.7	60.8	63.3	63.4	63.7	70.2	67.5		
Standard deviation	$S_{\bar{x}}$	0.40	0.10	0.26	0.37	0.39	0.66	0.85	0.94	1.43	1.67	0.71		
Average weight lb				2.78	3.51	3.90	4.54	5.15	5.11					

An Anomalous Increase of Temperature in the Ocean off the Pacific Coast of Canada through 1957 and 1958[1]

By J. P. Tully, A. J. Dodimead and S. Tabata

Fisheries Research Board of Canada
Pacific Oceanographic Group, Nanaimo, B.C.

ABSTRACT

The temperature increase extended from the surface to nearly 500 m depth. Its progress is shown by temperature distribution on the isopycnal surface, $\sigma_t = 26.60$, which is in the halocline, immediately below the depth of seasonal influence. During this period the currents veered northward and strengthened. The spawning migration of sockeye salmon (*Oncorhynchus nerka*) in the ocean was shifted northward and delayed in association with these anomalous oceanographic conditions.

INTRODUCTION

Calloway and Mendiola (1957, 1958) have prepared mid-monthly charts of the anomaly of sea surface temperatures from the 30-year mean charts (No. 225) of U.S. Navy Hydrographic Office (1944). Copies of their mid-winter and mid-summer charts in the eastern sub-Arctic Pacific are reproduced in Fig. 1 and 2. These data show that the water off the Canadian coast was cooler than normal in February 1957[2]. During the following summer it became warmer than normal near the coast. During 1958 the area of warming extended further seaward.

It is evident from these charts that departures from the mean surface temperatures are localized, and that the area and intensity of the anomalies increase and decrease non-seasonally. Such behaviour is more likely to be associated with water movements than with surface heating and cooling.

Data are available to examine the occurrence and development of the anomaly off the Pacific coast of Canada.

Quasi-synoptic oceanographic surveys have been made in the eastern sub-Arctic Pacific Ocean in four successive summers since 1955, and two successive winters since 1957 (Pacific Oceanographic Group, 1956, 1957a, 1957b, 1957c, 1958a, 1958b, 1958c). These are augmented with data collected by Scripps Institution of Oceanography (1956), U.S. Fish and Wildlife Service (McGary *et al.*, 1956), and the University of Washington (1957, 1958). These data have been analyzed to show the properties of the water and the geostrophic currents. These have been aided by drift bottle observations from 1956 through 1958 (Dodimead and Hollister, 1958).

[1]Received for publication March 26, 1959.

[2]Calloway and Mendiola indicated that the water off the Canadian coast was 8°F (4.5°C) colder than the 30-year mean. However, Canadian data in the same region showed that the anomaly was less than 2°F (1°C).

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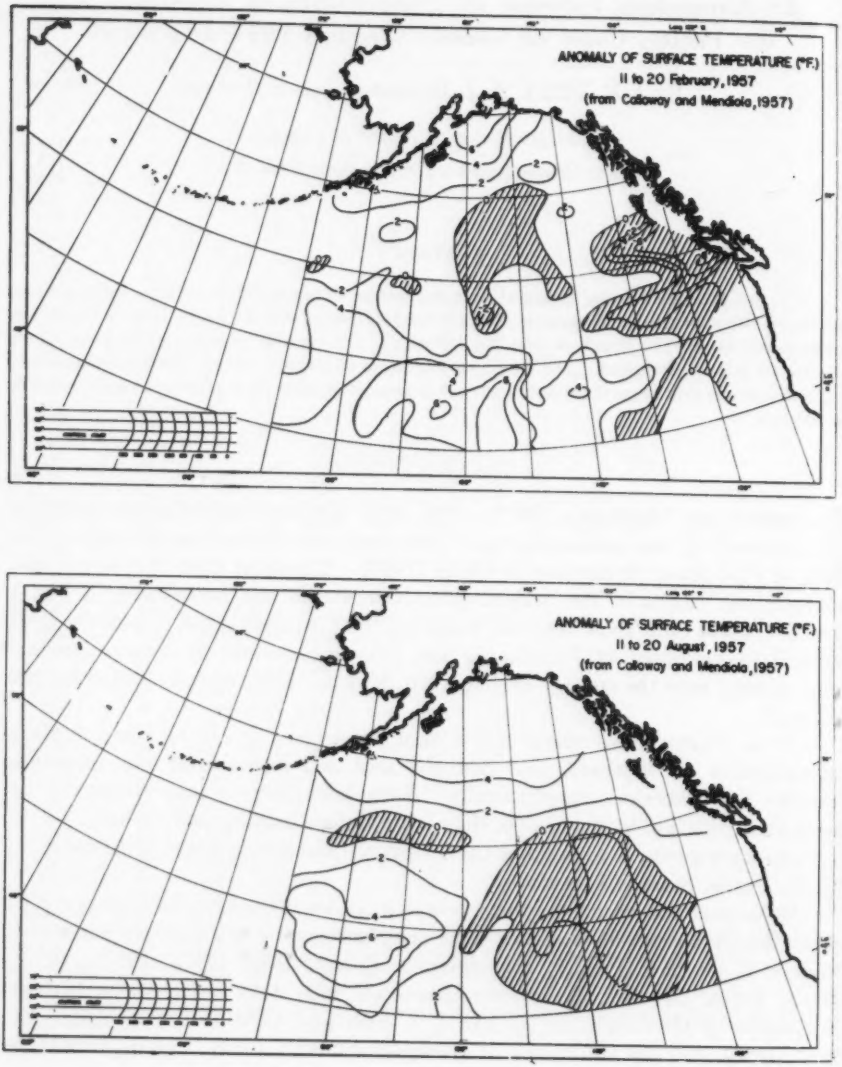
ANOMALY OF SURFACE TEMPERATURE (°F.)
11 to 20 February, 1957
(from Calloway and Mendiola, 1957)
ANOMALY OF SURFACE TEMPERATURE (°F.)
11 to 20 August, 1957
(from Calloway and Mendiola, 1957)

FIG. 1.

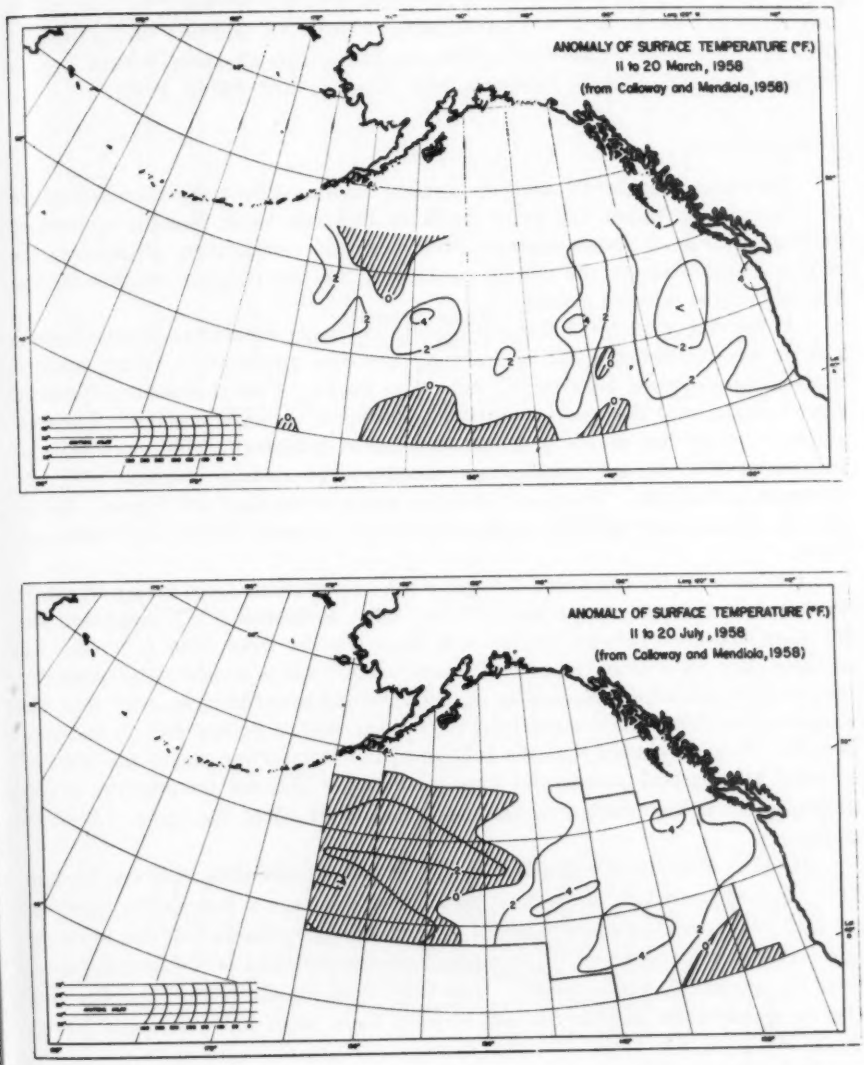
ANOMALY OF SURFACE TEMPERATURE (°F.)
11 to 20 March, 1958
(from Calloway and Mendiola, 1958)
ANOMALY OF SURFACE TEMPERATURE (°F.)
11 to 20 July, 1958
(from Calloway and Mendiola, 1958)

FIG. 2.

Bathythermograph (BT) observations of temperature structure to 135 m depth have been made twice daily at Ocean Weather Station "P" (lat. 50°N, long. 145°W) since July 1952 (Hollister, 1956). In addition comprehensive oceanographic observations have been made through alternate 6-week periods since August 1956 (Pacific Oceanographic Group, 1957d, 1958d, 1959).

Temperature

The seasonal cycle of heating and cooling dominates the temperature structure of water in the upper 120 m of depth in this sub-Arctic domain. The first diagram in Fig. 3 shows representative seasonal temperature structures, the second diagram shows the annual cycle, and the last diagram emphasizes the annual cycle at selected depths.

At the end of winter (February–March) the upper waters to a depth of about 120 m are isothermal. Spring warming becomes apparent in April, when a thermocline develops between 10 and 50 m depth. This thermocline becomes more intense, and deepens, as warming continues through summer. Through autumn and winter it becomes less marked and deeper, until it vanishes in February. The annual temperature range at the surface is about 8°C but decreases with depth. At about 120 m the range is less than one degree. Below this the temperature variation appears to be non-seasonal (Tully and Dodimead, 1957).

Hollister (1956) examined the daily BT observations from Ocean Weather Station "P" through the period 1952 to 1955. Robinson (1957) examined the BT data collected throughout the sub-Arctic Pacific from 1944 to 1950. All of these data show that the annual temperature cycle is consistently recurrent, the range of seasonal variation is nearly constant over the area, and that the temperatures below the deepest level of the thermocline do not vary in seasonal periods. It is concluded that the bottom of the thermocline marks the limit of seasonal heating and cooling and wind mixing, and that the temperature in the deeper water is independent of these processes that affect the upper 120 m of water.

The first diagram of Fig. 4 shows surface temperature data at Ocean Station "P". Superimposed on the annual cycle there has been a progressive warming through 1957 to mid-summer 1958. The second diagram shows that this warming also occurred at 61 m depth. These data are representative of the seasonal zone, from the surface to 120 m depth. The third diagram shows that the warming also occurred below this, in the non-seasonal zone, from 125 to at least 500 m depth.

It is of some interest to determine the extent of the anomaly elsewhere in the area. Since it has been shown that the warming extended below the level of seasonal influence, its extent can be determined by an examination of the data in the non-seasonal waters.

It is observed that there are ambient variations of the temperature and other properties of the sea water at any fixed depth, because of internal waves and other

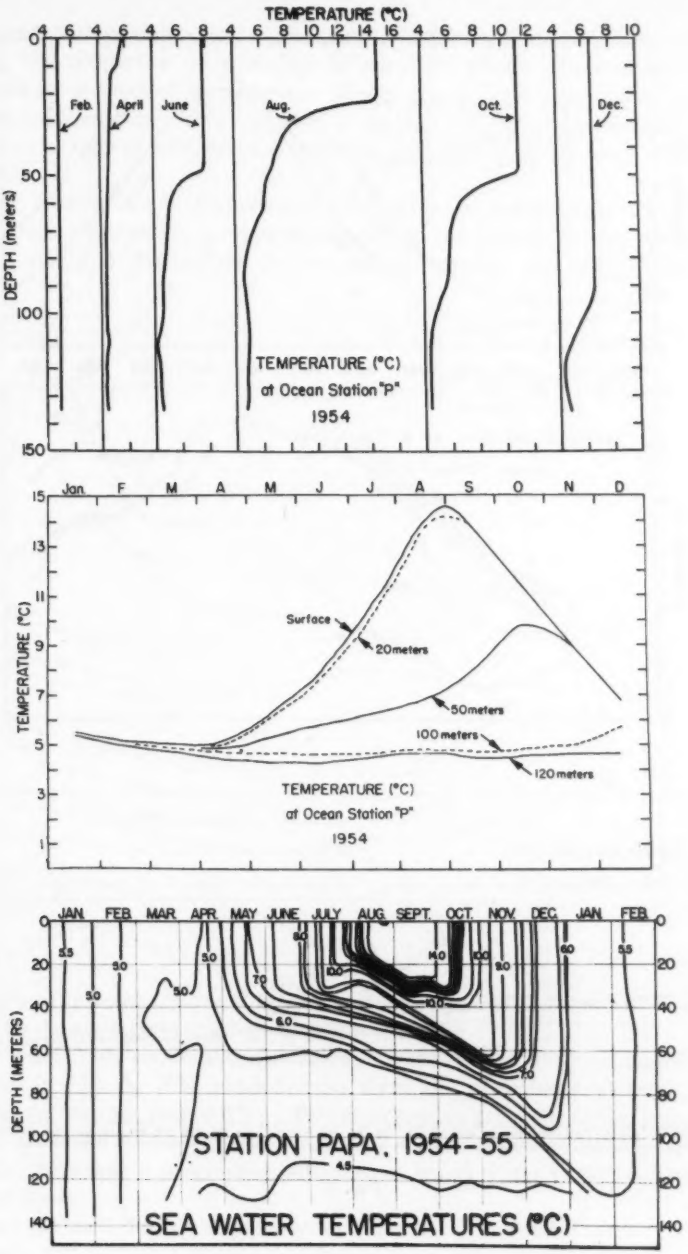
TEMPERATURE (°C)
DEPTH (meters)
Feb.
April
June
Aug.
Oct.
Dec.
TEMPERATURE (°C)
at Ocean Station "P"
1954
Jan. F M A M J J A S O N D
TEMPERATURE (°C)
Surface
20 meters
50 meters
100 meters
120 meters
TEMPERATURE (°C)
at Ocean Station "P"
1954
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC. JAN. FEB.
DEPTH (METERS)
STATION PAPA, 1954-55
SEA WATER TEMPERATURES (°C)

FIG. 3.

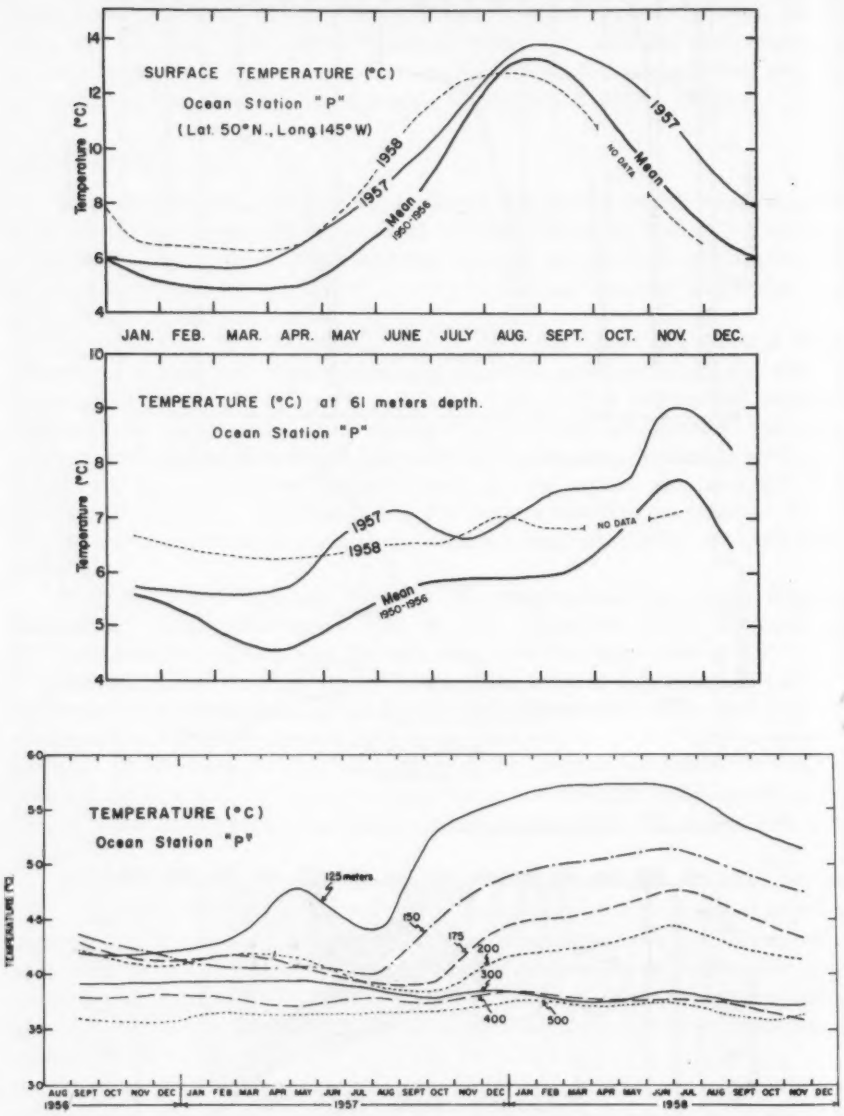
SURFACE TEMPERATURE (°C)
Ocean Station "P"
(Lat. 50°N., Long. 145°W)
1958
1957
Mean 1950-1956
NO DATA
Mean
Temperature (°C)
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
TEMPERATURE (°C) at 61 meters depth.
Ocean Station "P"
1957
1958
NO DATA
Mean 1950-1956
Temperature (°C)
TEMPERATURE (°C)
Ocean Station "P"
125 meters
150
175
200
300
400
500
AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEPT OCT NOV DEC
1956 1957 1958

FIG. 4.

disturbances within the water mass. Such variations can be eliminated by observing the properties on a surface of constant density, because its depth varies with these internal movements. Hence the temperature at any location on an isopycnal surface, below the level of surface influence, identifies the water mass. Any change of temperature betokens a change of water mass (Sverdrup *et al.*, 1942).

In the present case it is convenient to examine the temperature distribution, observed during successive surveys on the surface of constant density $\sigma_t = 26.60$.* As shown in Fig. 5 this surface lies everywhere between 125 and 225 m depth

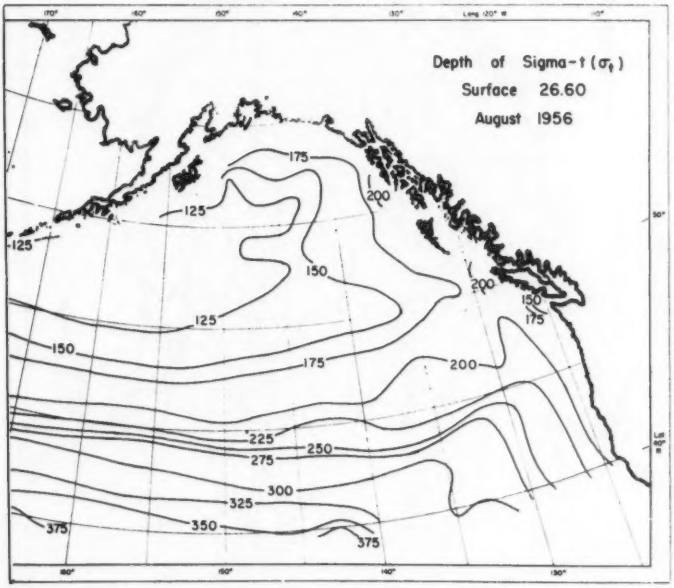

FIG. 5.

in the area of interest. Thus it is always below the depth of seasonal influence, and all the data are comparable, regardless of season.

The data from six consecutive surveys from August 1955 to August 1958 are shown in Fig. 6. The shaded areas show the progressive increase of the area of water warmer than 6.5°C. This corresponds precisely to the area of the warming anomaly defined at the surface by Calloway and Mendiola (Fig. 1). Evidently there was a progressive intrusion of warm water northward past the Canadian coast.

Proof of this deduction requires an examination of the ocean currents through the period.

*σ_t = (specific gravity − 1) × 1000, hence σ_t = 26.60 corresponds to specific gravity 1.02660.

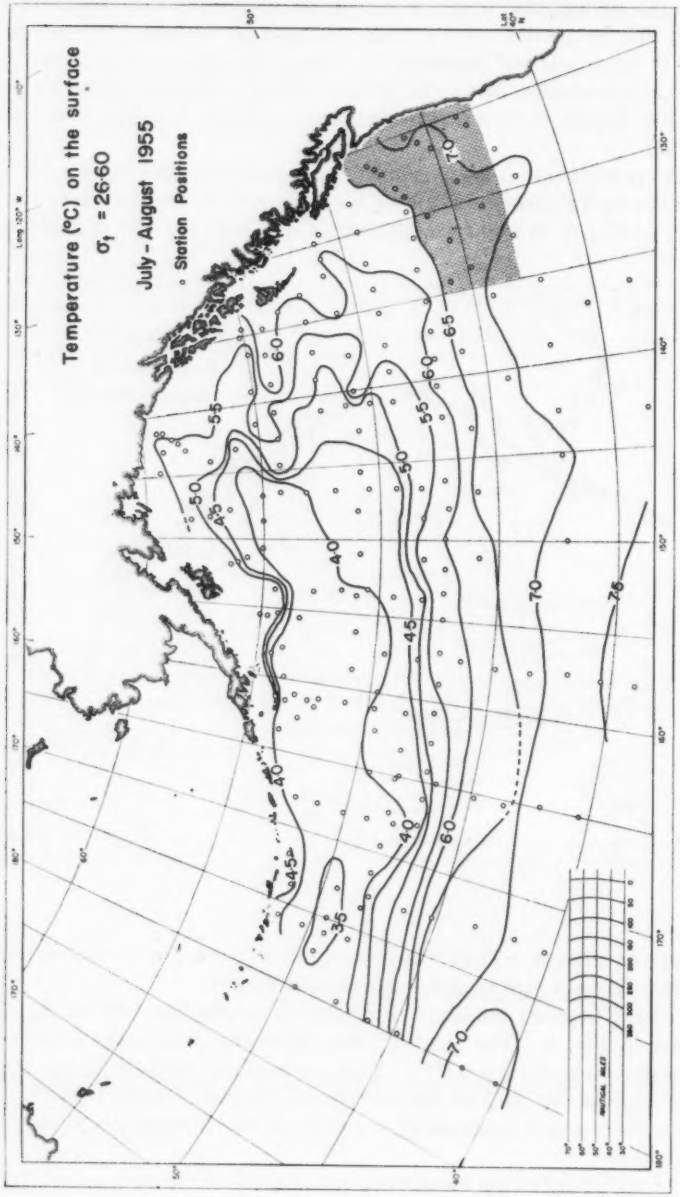

FIG. 6 (cont'd on following pages).

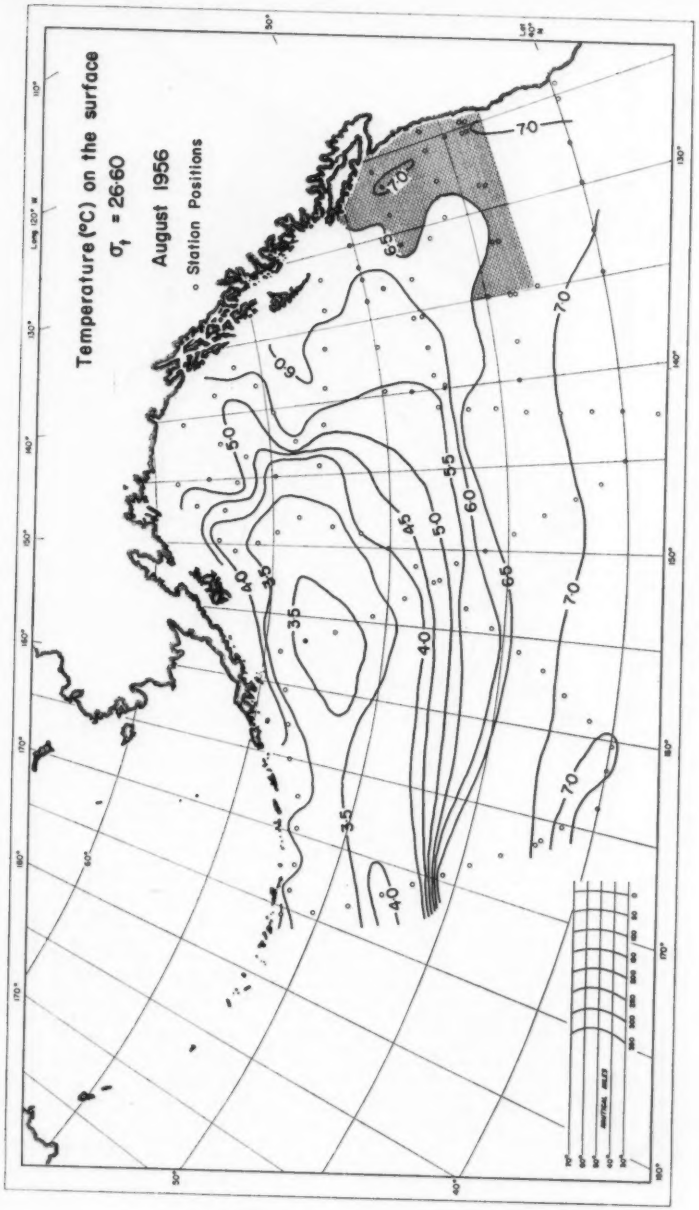
Temperature (°C) on the surface
σ_t = 26·60
August 1956
Station Positions
70
70
60
50
55
60
65
70
45
50
40
35
35
40
35
40
70
70
70

FIG. 6 (cont'd).

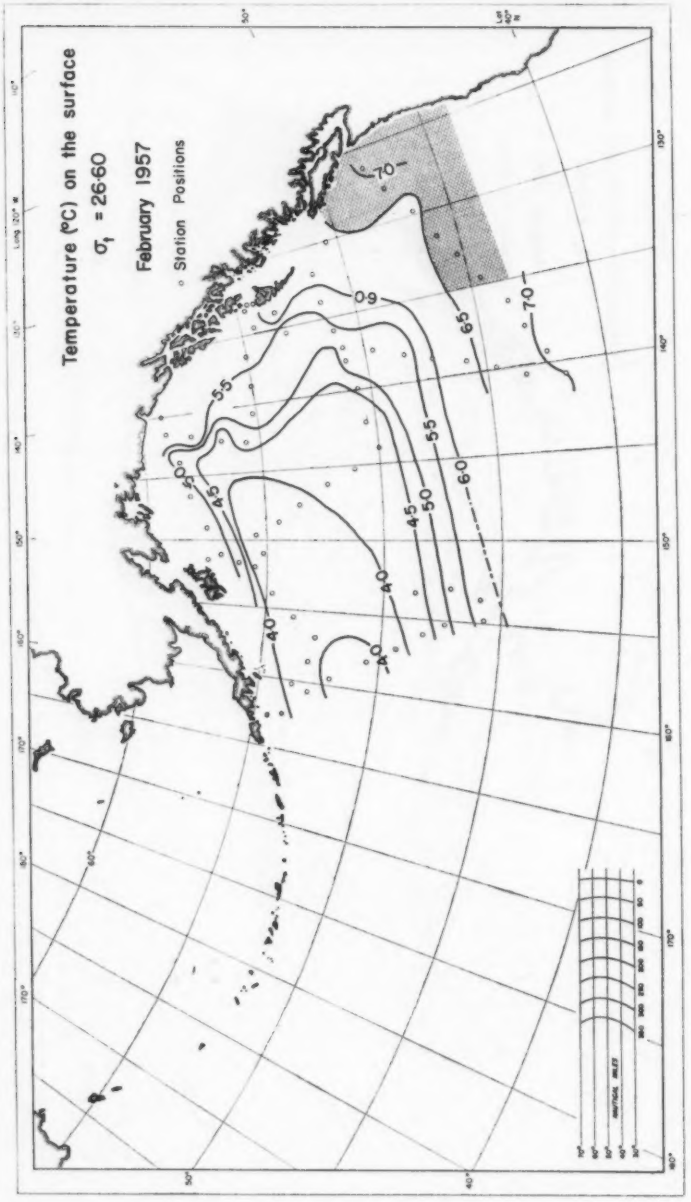
Temperature (°C) on the surface
σ_t = 26·60
February 1957
Station Positions
70
09
65
55
55
60
50
45
40
40
40
55
70

FIG. 6 (cont'd).

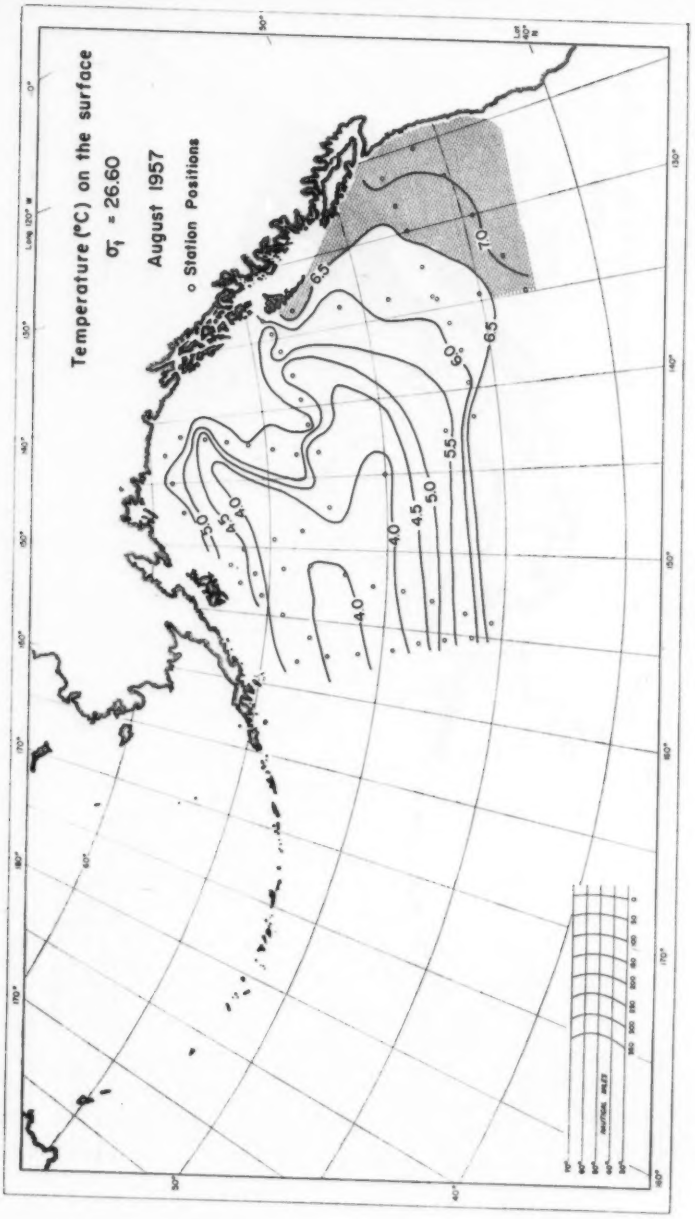
Temperature (°C) on the surface
σ_t = 26.60
August 1957
o Station Positions
6.5
7.0
6.0
6.5
5.5
5.0
4.5
4.0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
NAUTICAL MILES

FIG. 6 (cont'd).

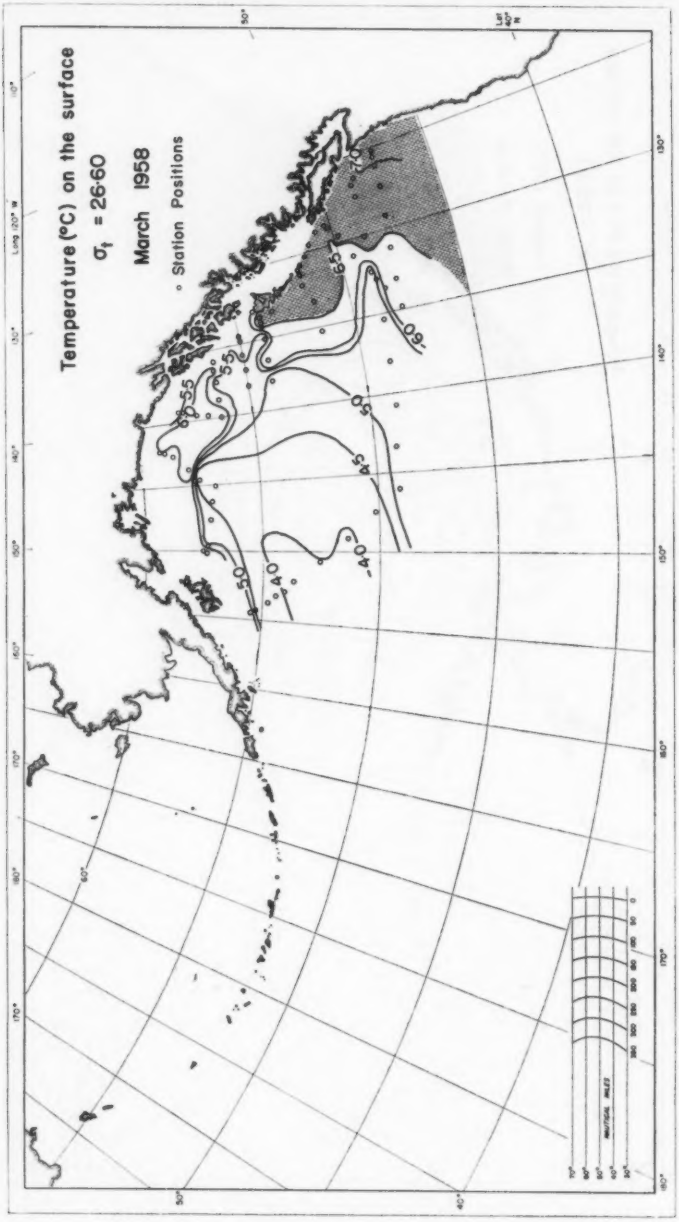
Temperature (°C) on the surface
σ_t = 26·60
March 1958
Station Positions
·70
·65
·60
·55
·50
·45
·40
·35
·30
·25
·20
·15
·10
·05
·00
NAUTICAL MILES

FIG. 6 (cont'd).

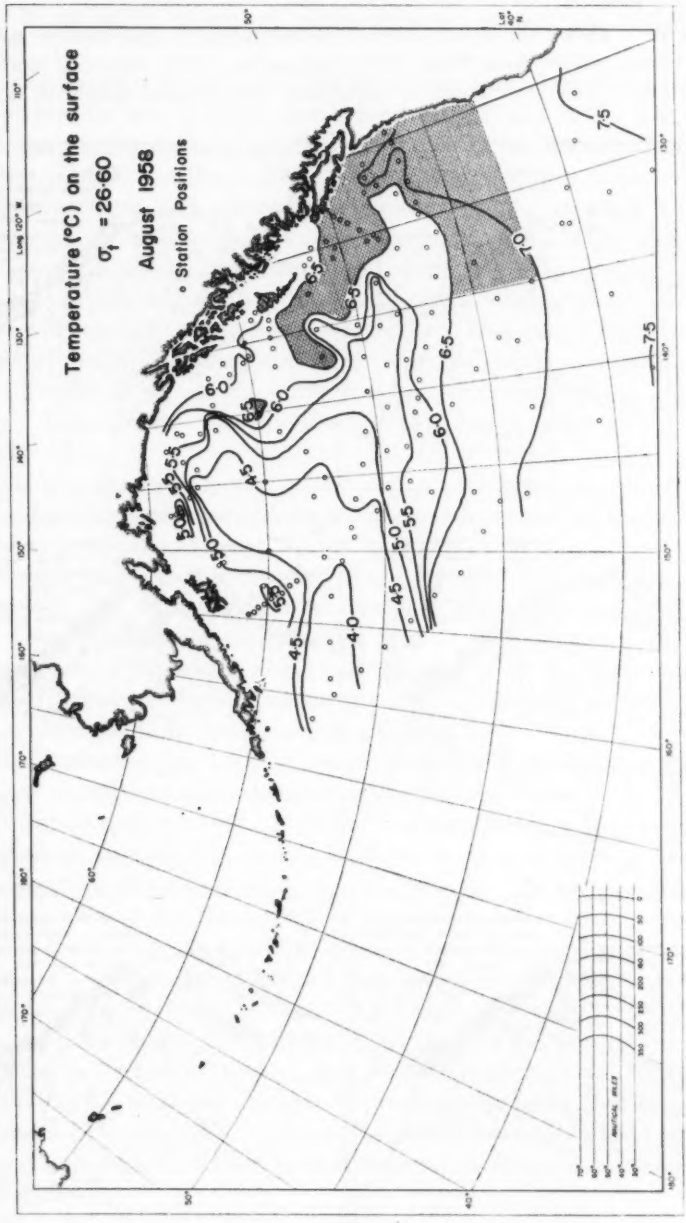
Temperature (°C) on the surface
σ_t = 26·60
August 1958
• Station Positions
Long 120° W
50°
40°
110°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
60°
50°
40°
6·0
6·5
5·5
5·0
4·5
4·0
7·0
7·5

FIG. 6 (cont'd).

Ocean Currents

Figure 7 shows the ocean current configuration in the eastern sub-Arctic Pacific Ocean. The West Wind Drift approaches North America more or less latitudinally. Near the coast it separates. Part turns south to form the

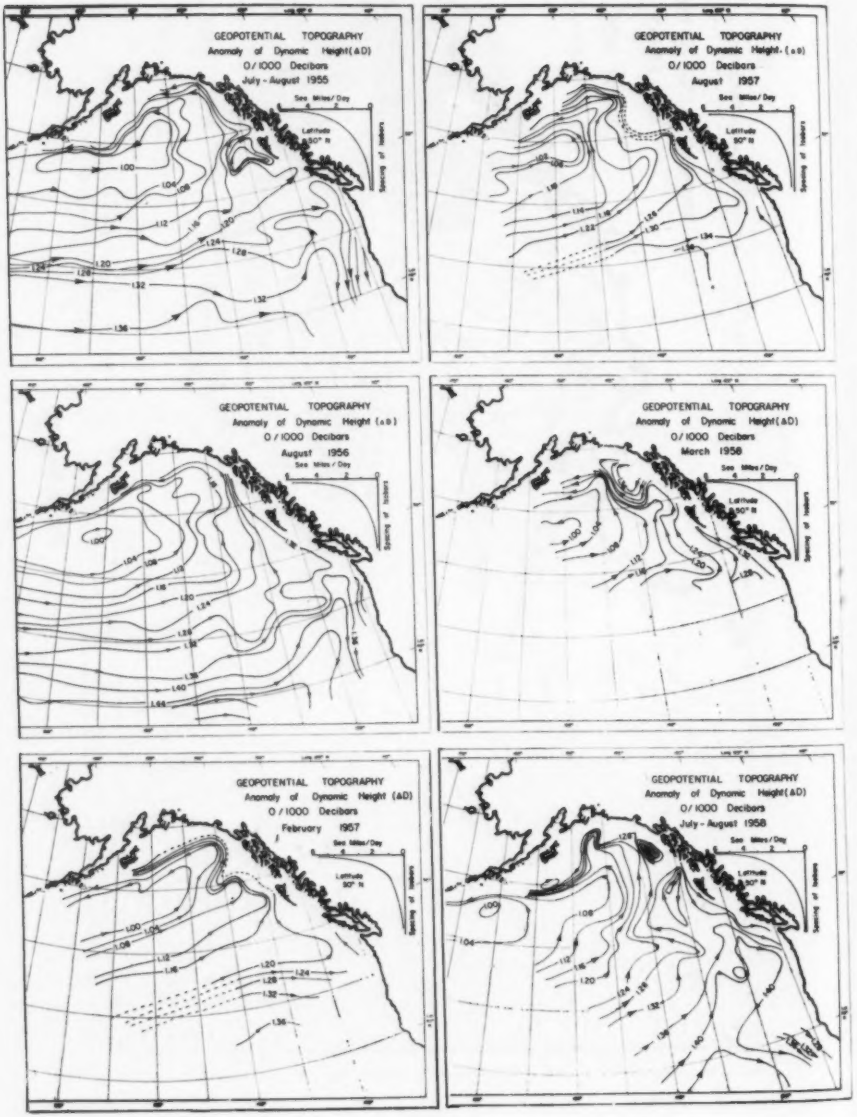

Fig. 7.

California Current, and part turns north to form the Alaska Gyral (Sverdrup *et al.*, 1942). In the region of separation the currents are weak and variable (Doe, 1955).

In the summers of 1955 and 1956 the stream lines destined for the Alaska Gyral entered the area from the west between lat. 45° and 50°N. The flow was almost due easterly past Ocean Weather Station "P". Between August 1956 and February 1957 the direction of the current veered slightly toward the north. This northward tendency increased progressively until August 1958 when the flow was due north. During this period the point of separation of the waters moved south. In consequence more and more water from south of lat. 45°N entered the Gyral, and the flow increased. These conclusions have been confirmed by drift bottle experiments (Dodimead and Hollister, 1958).

Bennett (1959) studying the 1955 (NORPAC) data concluded that the general circulation pattern below the seasonal zone was similar to that at the surface. This coincides with the recognition of the anomaly to 500 m depth at Station "P".

Evidently the anomaly may be regarded as a result of a northward intrusion of water from the surface to at least 500 m depth, between Station "P" and the coast, during the period January 1957 to August 1958.

The last stages of this intrusion are of interest. The isopycnal chart for August 1958 (Fig. 6) shows that the intruding waters had separated from the coast. The corresponding current chart (Fig. 7) shows that the major north-flowing stream of the Alaska Gyral had moved west to the vicinity of Station "P" and a south-flowing countercurrent had developed along the coast. A cyclonic eddy system lay between these currents.

Also, during the year 1958 the western boundary of the intruding water mass developed undulations (perturbations), and elements (clouds) broke off the apex and drifted around the Gulf of Alaska. Obviously this is the mechanism of dissipation of the intruding water. However it is not possible to follow these developments in the semi-annual data. Evidently the time scale of this behaviour is less than the 6 months separating the surveys. Considering the rate of transport, it is probable that perturbations develop and break off as clouds in about a month to 6 weeks. More frequent observations are required to confirm this.

In this location, where the West Wind Drift separates into the California Current and the Alaska Gyral, it is implied that the dynamic surface must be higher than in the Gulf of Alaska. It is intuitively apparent that such a "High" will shift readily with any changes in the causative forces such as latitudinal wind stresses (Munk, 1950). Hence the current pattern must be undergoing continual adjustment. Evidently this observed intrusion is a consequence of such a shift.

It may be surmised that the causative forces and the circulation will eventually readjust toward normal. When this occurs the intrusion will cease, and the

anomalous water will be dissipated by transport around the Gulf of Alaska. There is some evidence, in the temperature data from Station "P", that the break-up had begun in August and September, 1958. The surface waters had become cooler than the mean, and this cooling tendency was also apparent in the non-seasonal zone, below 120 m depth.

This whole sequence of anomalous intrusion has not been observed before. However, the southerly flow in an area extending 100 miles off Vancouver Island was observed in the summer of 1936 (Tully, 1937). This could have been the end phase of a similar warm water intrusion. No such condition was observed during the surveys of 1950, 1951, and 1952, in the same area (Doe, 1955). Nor is there any evidence of such an extensive anomaly in the BT data from Station "P". However, there is no physical reason why the anomaly should not recur. It can only be concluded that its occurrence, at least to this degree, is infrequent. No doubt similar occurrences to lesser degree are included in the accepted range of variation of oceanographic conditions.

The observation of the phenomenon during the past 3 years has provided a model of the oceanographic mechanism and structure in the region of the division of the West Wind Drift current, a model which was not available previously. This warrants further study with a view to numerical forecasting of the oceanographic conditions in the area. This is of some economic value because of the effects on the fisheries in the area.

SOME EFFECTS ON THE FISHERIES

Sockeye Salmon Migration

Sockeye salmon (*Oncorhynchus nerka*) are the most valuable of the commercially caught fishes along the Pacific coast of Canada. The largest single stock is popularly called the "Adams River Run". In 1958 it constituted five-sixths of the total Fraser River stock. These runs of sockeye to the Fraser River have been the subject of intensive study since 1937 by the International Pacific Salmon Fisheries Commission, whose Director, Lloyd A. Royal, has provided the following details of life history and behaviour.

The adult Fraser River sockeye are predominantly 4 years old (4_2). There is a major run every fourth year (e.g. 1954, 1958) and minor runs occur in the intervening years.

The eggs are spawned in the summer and autumn and hatched in the following spring. The young spend a year in an adjacent lake and migrate down the Fraser River to the Pacific Ocean. There they spend 2 years. With the onset of sexual maturity the fish return to the ocean coast. Normally, they first appear in the commercial troll fishery off the West Coast of Vancouver Island, as shown by the 1954 data in Fig. 8. From there the great majority approach

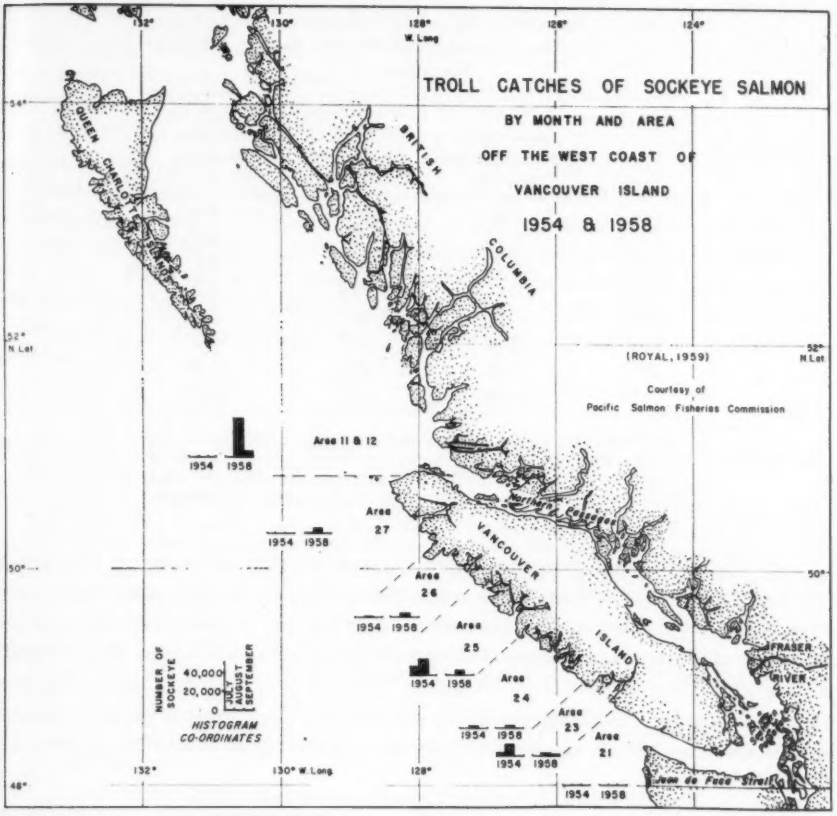

FIG. 8.

the Fraser River by way of Juan de Fuca Strait and the southern passages. The peak abundance of the Adams River Run enters the river between September 15 and 20. Until 1957 the spawning migrations of Fraser River sockeye were remarkably regular.

The pertinent features of the spawning migrations since 1951 are shown in Table I. The Commission has shown that there is a close relation between the troll catch on the coast of Vancouver Island and the total run to the Fraser River. Comparison of Columns 2 and 3 of Table I show that there is a positive relation between the troll catch at the north end of the island and the catch in the northern passages. It is assumed (with the reservations noted in the Table) that these values are representative of the proportion of the run appearing off the north end of Vancouver Island and approaching the Fraser River by the northern passages.

TABLE I. Features of the sockeye salmon runs to the Fraser River. (Courtesy International Pacific Salmon Fisheries Commission.)

Year	Total catch plus escapement (millions)	Troll catch in Area 12 (% of West Coast catch)	Catch in northern passages (% of total)
1951	3.12	16.1	8.6
1952	3.20	19.7	8.9
1953	5.41	20.4	9.7
1954	12.11	1.8	1.2
1955	2.59	22.7	6.7
1956	2.74	24.7	5.4
1957	4.81	40.2	11.8
1958	14.69	76.7	22.8*

*In 1958 extra closed seasons and sounding tendencies of the Adams River run combined with a 7-day fishing week in Puget Sound results in the logical conclusion that at least 36.8% of the run entered by way of the northern passages.

In 1957 the minor spawning migration was slightly anomalous. The landfall was further north than usual, and about 12% of the fish approached the river by way of the northern passages. In 1958 the anomalous behaviour of the major run was more obvious. About 76% of the fish arrived at the northern end of Vancouver Island (Fig. 8) and at least 23% approached by way of the northern passages. Although statistics are lacking, it is probable that a considerable proportion of the run approached the coast further north than Area 12 (Fig. 8).

RELATION WITH ANOMALOUS OCEANOGRAPHIC CONDITIONS. When these salmon went to sea in 1955 and 1956 the normal sub-Arctic currents and waters were present off the approaches to Juan de Fuca Strait (Fig. 6, August 1958). The anomalous oceanographic conditions in this approach first developed in 1957 and were intensified in 1958.

It is possible that the fish detoured around the unfamiliar area of warm water intrusion in their usual approach, to make their coastwise migration in the cooler near-shore water (Fig. 6). Also, it may be supposed that the fish were shifted further northward than usual in the ocean, or their homeward migration was retarded by the currents, which veered northward and strengthened while they were at sea as shown by the sequence of diagrams in Fig. 7.

These are simple explanations of the anomalous behaviour and are consistent with all the observed facts. They may not be correct in detail, but there is very little doubt of the principal feature. The coastal approach of the Adams River salmon stock was shifted northward, in association with the anomalous intrusion of warm water off the Canadian coast.

Whale Fishery

The earlier whale fishery off the Canadian Pacific coast was revived in 1948 by the British Columbia Packers Ltd., Vancouver. Their director of operations, Dr C. R. Elsey, has provided the following information.

The catch of whales off the Canadian Pacific coast in 1958 was remarkably different to that of the previous 6 years. The finback whale catch was 573, as compared with a previous high of 240 and a previous 6-year average of 178. The relatively high catch of 1958 was achieved in spite of the fact that the catcher boats, for a 3-week period at the height of the finback whale abundance, were on a catch limit. However, sperm whales were remarkably scarce, the catch being a little more than half of the average catch for the past 6 years. It is possible that the changes in migration pattern were associated with the northward intrusion of warm water.

REFERENCES

Bennett, E. B. 1959. Some oceanographic features of the northeast Pacific Ocean during August 1955. *J. Fish. Res. Bd. Canada*, **16**(5): 367–435.

Calloway, R. J., and E. W. Mendiola. 1957, 1958. Anomaly of sea surface temperature (°F) from 30-year mean charts of H.O. 225. Mid-monthly charts prepared by Pacific Oceanic Fisheries Investigations, U.S. Fish and Wildlife Service, Honolulu, Hawaii.

Dodimead, A. J., and H. J. Hollister. 1958. Progress report of drift bottle releases in the northeast Pacific Ocean. *J. Fish. Res. Bd. Canada*, **15**(5): 851–865.

Doe, L. A. E. 1955. Offshore waters of the Canadian Pacific coast. *Ibid.*, **12**(1): 1–34.

Hollister, H. J. MS 1956. The program of bathythermograph observations at the Canadian Ocean Weather Station "PAPA" (50°00′N, 145°00′W). Fish Res. Bd. Canada, Pac. Oceanog. Group. 17 pp., 15 fig.

McGary, J. W., E. C. Jones and T. S. Austin. 1956. Mid-Pacific Oceanography Part IX, Operation NORPAC. *U.S. Fish and Wildlife Service Special Scientific Report*, Fisheries No. 168. 127 pp.

Munk, W. H. 1950. On the wind-driven ocean circulation. *J. Meterol.*, **1**(2): 79–93.

Pacific Oceanographic Group of the Fisheries Research Board of Canada. MS 1956. Physical, chemical and plankton data record, Project NORPAC, July 26 to September 1, 1955. 202 pp.

MS 1957a. Physical, chemical and plankton data record, North Pacific survey, July 31–September 2, 1956, with Appendix I, Marine salmon exploratory fishing surveys, May 22 to September 12, 1956. 191 pp.

MS 1957b. Physical, chemical and plankton data record, North Pacific survey, January 23 to March 4, 1957. 110 pp.

MS 1957c. Physical, chemical and plankton data record, North Pacific Survey, July 23 to August 30, 1957. MS Rept. Series (Oceanographic and Limnological) No. 4. 103 pp.

MS 1957d. Data Record, 1956, Ocean Weather Station "PAPA" (latitude 50°00′N, longitude 145°00′W). 122 pp.

MS 1958a. Physical, chemical and plankton data record, North Pacific Survey, March 11 to April 10, 1958. MS Rept. Series (Oceanographic and Limnological) No. 16. 220 pp.

MS 1958b. Physical and chemical data record, North Pacific Surveys, Western Aleutians and Bering Sea, June 27 to August 14, 1958. *Ibid.*, No. 28. 104 pp.

MS 1958c. Physical and chemical data record, North Pacific Surveys, Continental Shelf and Gulf of Alaska, July 22 to August 16, 1958. *Ibid.*, No. 29. 107 pp.

MS 1958d. Data Record, Ocean Weather Station "PAPA", (latitude 50°00′N, longitude 145°00′W) January 1, 1957–January 24, 1958. *Ibid.*, No. 14. 261 pp.

MS 1959. Data Record, Ocean Weather Station "P" (latitude 50°00′N, longitude 145°00′W) January 22–July 11, 1958. *Ibid.*, No. 31. 112 pp.

ROBINSON, MARGARET K. 1957. Sea temperature in the Gulf of Alaska and in the northeast Pacific Ocean, 1941–1952. *Bull. Scripps Institution of Oceanography, U. of California*, 7(1): 1–98.

SCRIPPS INSTITUTION OF OCEANOGRAPHY, UNIVERSITY OF CALIFORNIA. MS 1956. NORPAC Hydrographic Data. S.I.O. Reference 56–4.

SVERDRUP, H. U., M. W. JOHNSON AND R. H. FLEMING. 1942. The oceans, their physics, chemistry and general biology. Prentice-Hall, Inc., New York. 1087 pp.

TULLY, J. P. 1937. Gradient currents. *Fish. Res. Bd. Canada, Pacific Prog. Rept.*, No. 32, pp. 13–14.

TULLY, J. P., AND A. J. DODIMEAD. MS 1957. Canadian oceanographic research in the northeast Pacific Ocean. Fish. Res. Bd. Canada, Pac. Oceanog. Group. 11 pp.

UNIVERSITY OF WASHINGTON, DEPARTMENT OF OCEANOGRAPHY. 1957. Northeast Pacific Ocean physical and chemical data. Summers of 1955 and 1956. A preliminary tabulation of oceanographic data collected by M.V. *Brown Bear* and M.V. *John N. Cobb*. Tech. Rept. No. 55. 104 pp.

MS 1958. Northeast Pacific Ocean, physical and chemical data, Summer 1957.

U.S. NAVY HYDROGRAPHIC OFFICE. 1944. World atlas of sea surface temperatures. Second Edition—1944. H.O. Pub. No. 225. Washington, D.C.

Effect of the Ingestion of *Triaenophorus* Plerocercoids on the Nutritional Characteristics of Whitefish Fillets in the Rations of Puppies[1,2]

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ABSTRACT

To learn whether or not the ingestion of the cysts would affect the growth, the feed consumption, or the efficiency of feed utilization, 118 newly weaned puppies have been fed in 3- and 4-week trials on diets composed of meat or fish, with and without supplements of a meal mixture, to which in different tests *Triaenophorus crassus* plerocercoids were added in amounts up to 80 cysts per pound of fish. The levels of plerocercoids ranged from 0.39 to 66.0 per pup per day, equivalent to 1.56 to 264.0 cysts per day for an average man consuming 3000 dietary Calories in 24 hours. Although some tendency toward reduced feed efficiency for growth was observed at the maximum level of ingestion, due probably to a low energy value of the diet (which in this case consisted almost entirely of the cystic material), no statistically significant effect of the *T. crassus* additions to the basal diets could be detected in these studies. It is concluded that fish fillets contaminated with *T. crassus* have no detrimental effect on the growth of puppies and presumably the accidental ingestion of such fillets by man would be of no consequence nutritionally.

INTRODUCTION

Severe infestations of *Triaenophorus crassus* (tapeworm) in whitefish taken from certain freshwater lakes and rivers in Manitoba have resulted in heavy losses to members of the fishing industry attempting to place contaminated fish on the domestic or export market. Although *Triaenophorus* is not considered to be a parasite of man, the presence of these cysts renders the fillets unacceptable to the consumer on aesthetic grounds. However, there is also a possibility that the cysts may have some influence on the nutritive value of the fish other than possibly to cause a simple reduction in palatability. The investigation reported here was undertaken to determine whether these cysts may, in fact, either render the fish toxic or, to a lesser degree, exert an adverse effect so as to disturb growth, appetite or digestive and metabolic processes.

Young puppies were chosen as the experimental animals and were used in a series of three feeding trials wherein cyst concentration was varied from 0 to 30 per pound of fish, and in a toxicity trial wherein 80 cysts per pound of fish were fed. The effects of feeding cooked cysts, and of feeding the infected fish or uninfected fish + cyst mixture in combination with a dog meal, were also determined.

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[2]This study was carried out under contract to the Fisheries Research Board of Canada.

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EXPERIMENTAL

Although the four experiments varied as to design, duration and purpose, management procedures were generally standard. Pups were placed on test at approximately 10 weeks of age and allowed feed and water to appetite. In all experiments but the second the required diets were mixed in quantity immediately prior to the initiation of the test and subsequently stored as frozen blocks of appropriate size until withdrawn for feeding. Use of separate pens permitted a measure of individual weekly feed consumption to be coupled with concurrent data on weight gains.

EXPERIMENT I

Either ground beef round or raw whitefish fillets classified as to degree of *Triaenophorus* infestation (0, 1 to 9, or 10 to 19 cysts per fillet) formed the basis of the rations fed in the initial experiment, which was carried out in two replications, each of 21 days duration. Table I shows the lot numbers associated with each ration type and the percentage composition of the diets fed.

TABLE I. Composition of four rations fed to puppies (Experiment I).

Ingredient	Ration type			
	Fresh meat (Lots 1,5)	Fresh fish fillets (Lots 3,6,7)	Meat + meal[b] (Lot 2)	Fish + meal[b] (Lots 4,8,9)
	%	%	%	%
Meat	97	–	48.5	–
Fish	–	97	–	48.5
Dog meal[a]	–	–	50	50
Bone meal	2	2	1	1
Iodized Salt	1	1	0.5	0.5

[a]Macdonald College dog meal composed of 2 parts calf starter to 1 part early-weaning pig starter.

[b]Percentage composition on dry basis: mixing formula consisted of 4 parts fresh chopped meat (or fillets) plus 1 part dog meal.

EXPERIMENT II

This 28-day trial, which involved feeding a higher concentration of cystic material than in Experiment I, was set up in a $2 \times 2 \times 2$ factorial design, the comparisons being cooked vs. uncooked cysts, 0 vs. 30 cysts per pound of fish, and no meal vs. a 50% fish + 50% meal mixture. The method of feeding cysts, however, was revised in that appropriate quantities of cysts cut from *Triaenophorus*-bearing fish were added to uninfected fillets. Although true filleting of the *Triaenophorus*-free fish was considered to be impractical with facilities at hand, the head, tail and spinal column were removed in each case. The remaining bones were broken up in grinding and apparently presented no problem when ingested by the dogs.

The diets which did not contain meal were composed of 2% "20-Phos", 1% salt and 97% clean fish or clean fish + cysts. To form the diets containing meal, equal parts of this ration and Macdonald College dog meal were mixed. Although the cyst level in such diets remained at 30 per pound of fish, the concentration of cystic material in the total diet was essentially halved. Where called for in the design, cysts were cooked by steaming for 60 minutes.

EXPERIMENT III

Forty puppies were allotted to five treatment groups differing only in the numbers of *Triaenophorus* plerocercoids added to each pound of uninfected fish. The levels chosen were 0, 3, 6, 12, and 24 cysts per pound of fish and the total ration was compounded in such a manner that its "nutrient" makeup approximated that of the diet normally consumed by North Americans. Table II presents the percentage composition of the resultant product as compared to that of the "average" human diet.

TABLE II. Composition of ration fed to pups in Experiment III and comparison of its proximate principles with those of the average human diet consumed in North America.

Ration components	Proportion	Nutrient composition					Energy value	Proportion of total Calories
		Water	Fat	Protein	Ash	Carbo-hydrate		
	%	%	%	%	%	%	*Cal*/100 *g*	%
Fish	28	19.6	0.7	5.3	1.1	1.3	39	9.7
Macdonald College dog meal	57	4.0	2.3	13.4	5.7	31.6	228	56.7
Corn oil	15	–	15.0	–	–	–	135	33.6
Total	100	23.6	18.0	18.7	6.8	32.9	402	100.0
Av. human diet	–	10.0	20.0	15.0	5.0	50.0	–	–

EXPERIMENT IV

The 12 beagle puppies used in this toxicity test received a diet constituted of 1% "20-Phos", 1% iodized salt and 98% fish containing 80 cysts per pound. After 28 days, a veterinarian examined each dog *post mortem* and forwarded selected tissues to the Animal Diseases Institute, Hull, Quebec, for histopathological examination.

EXPERIMENTAL RESULTS

The average daily gains, dry matter intake and feed efficiency (grams feed required per gram gain) of the 31 pups which completed Experiment I have been compiled in Table III. The higher average initial weight of those pups in replication 1 is considered to be responsible for the observed discrepancy in gains and feed consumption between the two replications.

TABLE III. Average daily gains, feed intake and feed required per unit gain of puppies fed *Triaenophorus* cysts over a 21-day experimental period (Experiment I).

Replicate	Lot No.	Ration	No. dogs	Average initial weight	Average daily gain	Av. daily feed intake (dry matter basis)	Av. feed per gram gain[a]
				g	g	g	g
	1	Meat	5	4780	81	349	4.3
1	2	Meat + meal	4	4200	49	290	6.4
	3	Fish (1 to 9 cysts)	4	4663	64	253	4.0
	4	Fish (1 to 9 cysts) + meal	3	5003	50	296	6.0
	5	Meat	2	3125	49	198	4.2
	6	Fish (0 cysts)	3	2733	36	121	3.5
2	7	Fish (10 to 19 cysts)	3	2150	33	155	4.7
	8	Fish (0 cysts) + meal	4	2656	46	185	4.8
	9	Fish (10 to 19 cysts) + meal	3	3117	36	229	6.6

[a]Least significant difference between lots (for P = 0.05) = 2.0 g.

Palatability, judged on the basis of average feed consumption recorded in Table III, did not appear to be influenced by the addition of cysts to the fish or fish + meal rations. However, whenever the fish + meal combination was fed, the average daily dry matter intake increased over that of a comparable ration without meal, while feed efficiency (as indicated by feed required per unit gain) decreased. However, feed consumption cannot in this experiment be considered *per se*. In that the dry matter in diets composed almost entirely of fish was 30% as opposed to 60% in diets containing fish + meal, it is evident that the puppies would have had to compensate for this difference by increasing consumption where fish alone constituted the major portion of their intake. Although inspection of data for feed consumption on a moist basis shows that the pups actually consumed more of fish than of fish + meal rations, apparently intake was limited either by voluntary cessation or by satiation before sufficient had been consumed to equate intake with that of meal-containing diets when considered on a dry matter basis.

There appeared to be a trend toward decreased feed efficiency as the level of cysts contained in the fillets was increased. From the last column in Table III, the grams of feed required to produce one gram of gain are seen to increase from 3.5 at 0 cysts, through 4.0 at the 1 to 9 cysts level, to 4.7 when 10 to 19 cysts per fillet were fed. Similarly when the fish + meal combination is considered, the figures for feed per unit gain are 4.8, 6.0 and 6.6 g for 0, 1 to 9, and 10 to 19 cysts per fillet respectively. Analyses of variance of the data, however, failed to reveal any statistically significant differences between the mean efficiencies when cyst levels within ration type were compared.

The average daily gains of puppies on the various diets of Experiment II are recorded in Table IV. Statistical analysis showed no significant differences between the mean gains of groups on 0 vs. 30 cysts per pound of fish, cooked vs. uncooked cysts at the level of 30 per pound of fish, or no meal vs. the 50% meal +

TABLE IV. Average daily gains of groups of six pups fed cooked or uncooked *Triaenophorus* cysts over a 28-day experimental period (Experiment II).

Ration type	Cyst level (per pound of fish)					Mean values
	0	30 (Raw)	0	30 (Cooked)		
	g	g	g	g		g
Fish	51.5	64.6	58.3	59.8		58.6
Fish + meal	47.6	58.3	57.1	56.0		54.8
Mean values	49.6	–	57.7	—	53.7 g	56.7
	–	61.5[a]	–	57.9[a]	59.7 g	

[a]Least significant difference between groups of 12 (for P = 0.05) = 12.9 g.

50% fish combination. However when the average daily dry matter intake of the pups (Table V) was analyzed statistically, highly significant differences between cyst levels and between rations containing no meal and those containing 50% meal were revealed. The increased intake of dry matter when pups were fed 50% meal in the ration must, as in Experiment I, be examined with the relative moisture contents of the two diets in mind. Analysis showed the percentage of dry matter in fish + meal diets to be approximately twice that of rations containing fish alone. Although puppies on the latter dietary regime ate considerably more feed when the comparison is made on an air-dry basis, conversion of intakes to a dry-matter basis reversed their positions. Voluntary intake of the two diets containing cooked cysts was almost identical to that of the comparable rations containing uncooked cysts.

TABLE V. Average daily dry matter intake of groups of six pups fed cooked or uncooked *Triaenophorus* cysts over a 28-day experimental period (Experiment II).

Ration type	Cyst level (per pound of fish)					Mean values
	0	30 (Raw)	0	30 (Cooked)		
	g	g	g	g		g
Fish	147	171	144	168		158
Fish + meal	196	220	212	223		213
Mean values	172	–	178	–	175 g	186
	–	196[a]	–	196[a]	195 g	

[a]Least significant difference between groups of 12 (for P = 0.05) = 21 g.

The significant increase in consumption when cysts were fed would again indicate that acceptability of the ration was not adversely affected by this alteration in ration content.

When feed efficiency was calculated (Table VI) and analyzed statistically, no significant differences were found between cyst levels or between cooked and uncooked cysts. A highly significant difference was found, however, between puppies not receiving meal and those fed 50% meal, the feed efficiency in the former group being superior.

TABLE VI. Average feed efficiency (grams feed required per gram gain) of groups of six pups fed cooked or uncooked *Triaenophorus* cysts over a 28-day experimental period (Experiment III).

Ration type	Cyst level (per pound of fish)					Mean values
	0	30 (Raw)	0	30 (Cooked)		
	g/g	g/g	g/g	g/g		g/g
Fish	3.0	2.8	2.5	2.8		2.8
Fish + meal	4.3	3.8	3.9	4.2		4.1
Mean values	3.7	–	3.2	–	3.5 g/g	3.5
	–	3.3[a]	–	3.5[a]	3.4 g/g	

[a]Least significant difference between groups of 12 (for P = 0.05) = 0.6 g.

The general health of all puppies in this trial was considered to be normal with no digestive or other disturbances being observed.

Table VII summarizes data obtained in Experiment III relative to initial weight, gain, feed consumption and the efficiency with which ingested feed was converted to body tissue.

TABLE VII. Average daily gains, feed intake and feed required per unit gain of puppies fed *Triaenophorus* cysts over a 28-day experimental period (Experiment III).

Lot No.	Ration treatment	No. of dogs	Average initial weight	Average daily gain	Average daily feed intake (dry matter basis)	Average feed per gram gain
	cysts		g	g	g	g
1	0	8	2406	65	184	2.91
2	3	8	2275	47	160	3.80
3	6	8	2206	65	166	2.60
4	12	7	2264	49	159	3.36
5	24	8	2344	56	163	2.99

When individual values for the last three criteria were analyzed statistically, no significant differences between ration treatments were revealed. It would seem then that the addition of *Triaenophorus* cysts to an experimental diet revised to approximate that of the human in the amounts of protein, fat and carbohydrate contained therein does not alter the nutritional quality of such diets.

Because one pup contracted hepatitis and lost weight during the final week of Experiment IV, data from only 11 individuals are considered to be valid.

The average daily gain of this group was 27 g, the average daily feed intake 130 g, and the average feed required per gram gain was 5.08 g.

The attempt to induce a toxic reaction by feeding 80 cysts per pound of fish was unsuccessful. No abnormalities in appearance or behaviour were noted during the experimental period and autopsy indicated all internal organs, excepting kidneys in five instances, to be normal in the gross. Histological examination of the kidney tissue in question, however, did not reveal any marked disturbance or suggest any cause-and-effect relation between diet and the minor irregularities observed.

INTEGRATING DISCUSSION

On the basis of data accumulated in the three growth trials and the toxicity test, there is no evidence to suggest that the feeding value of whitefish fillets was impaired by the presence of *Triaenophorus* plerocercoids or that the feeding value of the cysts themselves was altered by cooking. Tables VIII and IX contain

TABLE VIII. Summary of data from groups of pups fed *Triaenophorus* cysts in conjunction with rations containing no meal in Experiments I–IV (meat-containing rations excluded).

Ration (cysts in terms of cysts per pound of fish)	No. of pups	Dry matter intake as proportion of initial weight	Average daily gain	Average feed per gram gain	Computed cysts eaten per pup per day
		%	g	g	
0 cysts; Expt. I Rep. 2	3	4.4	36	3.5	–
Expt. II	6	4.4	52	3.0	–
Expt. II	6	5.2	58	2.5	
1 to 9 cysts; Expt. I Rep. 1	4	5.4	64	4.0	9.3
10 to 19 cysts; Expt. I Rep. 2	3	7.2	33	4.7	16.5
30 cysts raw; Expt. II	6	5.8	65	2.8	38
cooked; Expt. II	6	5.4	60	2.8	37
80 cysts; Expt. IV	11	5.2	27	5.1	66

TABLE IX. Summary of data from groups of pups fed *Triaenophorus* cysts in conjunction with rations containing meal in Experiments I–III (meat-containing rations excluded).

Ration (cysts in terms of cysts per pound of fish)	No. of pups	Dry matter intake as proportion of initial weight	Average daily gain	Average feed per gram gain	Computed cysts eaten per pup per day
		%	g	g	
0 cysts; Expt. I Rep. 2	4	7.0	46	4.8	–
Expt. II	6	6.1	48	4.3	–
Expt. II	6	7.0	57	3.9	–
Expt. III	8	7.6	65	2.9	–
3 cysts; Expt. III	8	7.0	47	3.8	0.39
6 cysts; Expt. III	8	7.5	65	2.6	0.78
1 to 9 cysts; Expt. I Rep. 1	3	5.9	50	6.0	4.4
12 cysts; Expt. III	7	7.0	49	3.4	1.56
10 to 19 cysts; Expt. I Rep. 2	3	7.3	36	6.6	9.7
24 cysts; Expt. III	8	7.0	56	3.0	3.12
30 cysts, raw; Expt. II	6	6.9	58	3.8	12
cooked; Expt. II	6	7.4	56	4.2	12

data which, for comparative purposes, have been extracted from those obtained in Experiments I–IV and regrouped on the basis of cyst level and ration content (i.e. rations without meal, Table VIII; rations with meal, Table IX).

It will be noted that within each of these two Tables, values in the column headed "Dry matter intake as proportion of initial weight" are relatively constant, the chief exception occurring in Table VIII at the 10 to 19 cyst level. It would appear, therefore, that feed intake was largely a function of initial weight of the pups and that there was no discrimination exercised by them with respect to consumption of diets containing different amounts of cystic material. It follows, then, that variations in gain and feed efficiency are a reflection of the feeding value rather than the amounts of the ration eaten.

In previous discussions of individual experiments it was shown that, although feed efficiency appeared to be adversely affected in Experiment I as increasing levels of cysts were fed, this difference was not statistically significant nor was this trend borne out in Experiments II and III. Although feeding 80 cysts per pound of fish did not produce a toxic reaction, the performance of this group as shown in Table VIII was such that gains and feed efficiency were lower than those of other dogs fed rations without meal. However it is felt that the concentration of cystic material at this high level was probably so great as to reduce the feeding value of the ration by simple dilution rather than through the exertion of a deleterious effect on metabolic processes.

In connection with the final interpretation and evaluation of results from these feeding trials, some consideration of the degree to which *Triaenophorus* commonly infect whitefish is in order. Data presented by Oakland (1950) from two collections of Lake Winnipeg whitefish taken in August 1948 give cysts per fish as 1.18 and 0.96, with infection rates of 63.8 and 41.8 cysts per 100 lb of fish respectively. In June 1949, collections taken from an adjoining area on three successive days yielded 0.91, 0.22 and 0.69 cyst per fish (equal to infection rates of 42.1, 11.4 and 31.8 cysts per 100 lb of fish). Lawler (1956), in a 12-year compilation of data based on the catch from Heming Lake, Manitoba, has recorded cysts per 100 fish ranging from a low of 162 in 1956 to a high of 521 in 1945. The proportion of infected fish in the catch in 1945 was 82%, and in 1956, 37%. Tables of age–cyst distribution in whitefish from the Thunder Bay region of Ontario (Welch, 1952) show that 91% of the infected fish taken from Lake Muskeg in 1950 harboured 6 cysts or less, while 72% of the 1951 collection from Shakespeare Island Lake fell into this category. Age range of the Lake Muskeg fish was from 1 to 12 years; that of the fish from Shakespeare Island Lake, 1 to 20 years.

On the basis of these observations, it would appear that the highest level of cysts fed in the growth trial (30 cysts per pound of fish in a ration composed almost entirely of fish) was considerably beyond that which persons purchasing fish on the domestic market or fishermen consuming their own catch might encounter, and that 80 cysts per pound as fed in the toxicity trial would constitute what might be termed a "massive" dose. However, further calculations were carried out to estimate the average cyst intake of the pups on a daily basis and

thereby to eliminate the effect of differential consumption of the various rations. These computed levels of cyst intake, shown in the final column of Tables VIII and IX, fall over a wide range from less than one cyst in Experiment III (Table IX) up to 66 cysts in the toxicity test (Experiment IV; Table VIII). The ingestion of cysts where meal-containing rations are considered is less, of course, as a consequence of dilution of the fish + cyst mixture with this additional ingredient.

A further tabulation (Table X) was set up to compare the calculated intake of cysts per pup per day with the average and maximum potential intake of cysts by a person consuming a single contaminated fillet in any one day[3]. To

TABLE X. Comparison of potential daily ingestion of cysts by human subjects and calculated daily cyst intake of pups expressed on basis of equal daily Caloric intake (3000).

	Human subjects:		
Line	1	Average cysts per 100 lb of fish[a]	243
	2	Maximum cysts in one fish[a]	116
	3	Maximum cysts per pound of fish	105
	4	Average cysts per pound of fish	2.4
	5	Average cysts per fillet[b]	1.2
	6	Maximum cysts per fillet[b]	52
	7	Average cysts per person per day[b]	1.2
	8	Maximum cysts per person per day[b]	52
	9	Average cysts per 3000 Cal[c]	1.2
	10	Maximum cysts per 3000 Cal[c]	52
	Pups:		
	11	Average cysts per 750 Cal	0.39 to 66.0
	12	Average cysts per 3000 Cal	1.56 to 264.0

[a]Based on collections from Heming Lake, Manitoba, in 1945–56 (Lawler, 1956, table I).
[b]Assuming one fillet = ½ lb = 1 serving.
[c]Assuming average daily intake of 3000 Calories.

put this comparison on an equal basis, however, the calculated daily cyst intake of the pups as recorded in Tables VIII and IX has been multiplied by 4, the average caloric intake of the pups in our experimental series being ¼ that of the average person. By comparing the resultant figures, expressed on an equivalent Calorie basis for both pups and human subjects, it can be seen that the average number of cysts which might be consumed by a person ingesting one fillet (= one serving) of fish per day (line 9) is below the minimum number of cysts estimated to be consumed by pups in any of our experiments (line 12). Furthermore the maximum in this range of values for average cyst intake of pups on a 3000-Calorie basis is over 200 times the value for average potential human consumption (on line 9) and approximately five times the maximum number that a person might be

[3]One fish (after removal of viscera, head, tail, fins, skin and bones) is assumed to yield two fillets.

expected to ingest per day (line 10). The author feels, therefore, that failure to produce deleterious effects in pups by feeding *Triaenophorus* cysts in amounts many times in excess of the maximum potential level of contamination in the human diet underscores the negative results obtained at lower levels.

CONCLUSIONS

It is concluded that *Triaenophorus crassus* plerocercoids fed to pups in amounts up to 30 cysts per pound of ingested fish do not cause a statistically significant reduction in gains, feed consumption or efficiency of feed utilization, and that up to 80 cysts per pound of fish may be fed without inducing a toxic reaction. Although some tendency toward reduced feed efficiency was observed at the latter level, it is felt that this effect was an artificial one, being induced by dilution of the fish–bonemeal–salt mixture with cystic material to such an extent that the nutrient content of the ration as fed was insufficient to support normal growth.

REFERENCES

LAWLER, G. H. 1959. Biology and control of the pike–whitefish worm, *Triaenophorus crassus*, in Canada. *Fish. Res. Bd. of Canada, Prog. Rept. Biol. Sta. and Tech. Unit, London, Ont.* No. 1 pp. 31–37.

OAKLAND, G. B. MS 1950. Infestation rate studies. *Fish. Res. Bd. of Canada, MS Rept. of the Biological Sta.*, No. 486.

WELCH, H. E. MS 1952. Factors affecting the infection of the whitefish, *Coregonus clupeaformis* (Mitchill), by the tapeworm *Triaenophorus crassus* Forel, in the Thunder Bay District of Ontario. *Fish. Res. Bd. of Canada, MS Rept. of the Biological Sta.*, No. 523.

An Estuarine Analogy in the Sub-Arctic Pacific Ocean[1]

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ABSTRACT

It is shown that the features of an estuarine system occur northward of a sub-Arctic boundary in the Pacific Ocean.

The limit of downward mixing from the surface is the limit (L) of the halocline. This is defined by a discontinuity in the logarithmic plot of salinity structure, where the salinity is nearly constant ($33.8 \pm 0.1‰$). On this surface the transfer is uni-directional upward. Here the water masses being entrained into the halocline and upper zone may be identified by their temperature alone.

FEATURES OF AN ESTUARINE SYSTEM

The basic requirement for the establishment of an estuarine[2] system in any region is the presence of a supply of fresh water which exceeds the losses by evaporation or freezing.

Tully (1959) considered such conditions in coastal embayments (Fig. 1), observing that the fresh water moved persistently outward from the embayment at the surface, entraining sea water from below to form a transition zone (Tully, 1949) in which there is a halocline. The upper part of the halocline is usually nearly isohaline, because of mixing. It is called the upper zone, although it is considered to be part of the halocline. Both of these zones become progressively more saline along the path of outward flow, unless they are continually refreshed. Below the halocline is a lower zone in which the vertical and horizontal salinity gradients are small. Here, the motion is inward toward the source region.

Transport and Entrainment

It is concluded that fresh water entering the surface accumulates locally over the denser, more saline sea water, until a surface pressure gradient is established, sufficient to move the fresh water away from the source region at a rate equal to its supply.

The outward movement creates a velocity shear relative to the lower zone. This may be augmented by other shear stresses due to tides, winds, or current distribution. These shears provide the energy for mixing. Sea water mixed upward through the shear zone flows outward with the fresh water. Thus it is entrained and eventually lost from the region. It is replaced by an inward flow, toward the source region, below the shear zone. The density distribution in the halocline transition zone adjusts to provide the necessary inward pressure gradient force in the deeper water.

Fresh or mixed water transferred downward through the shear zone can

[1]Received for publication March 26, 1959.

[2]The term "estuarine" is used in the same sense as by Ketchum (1951) and Tully (1959) to refer to a region in which sea water is measurably diluted with fresh water.

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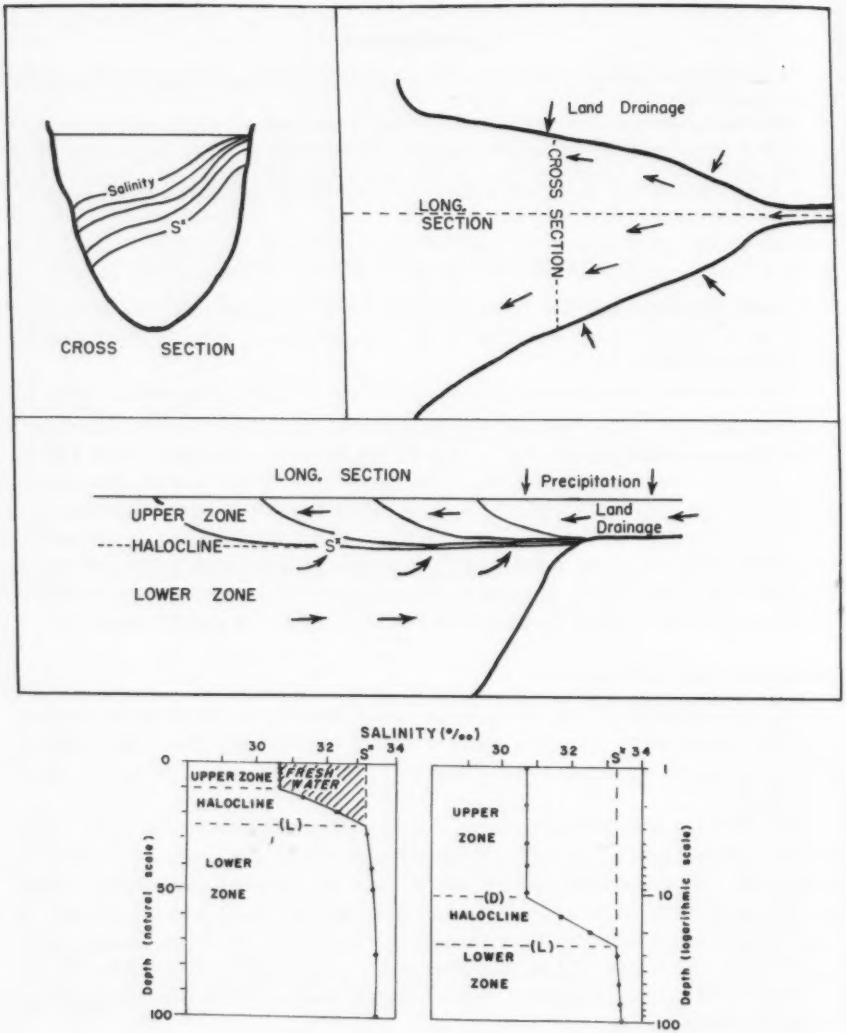
never attain the salinity (density) of undiluted sea water in the lower zone. Hence there is a limit of downward transfer of fresh (mixed) water which must be near the lower limit of the shear zone. This is defined in the structure (Fig. 1) by the lower limit L of the halocline. In this position the mixed water must be



FEATURES OF AN ESTUARINE EMBAYMENT

FIG. 1.

transported toward the source region, and be preferentially available for upward mixing.

Thus the entrainment process may be regarded as a uni-directional upward transfer of sea water, coupled with a random mixing process in the halocline. The lower limit L of the halocline is the limit of the random mixing feature. At this limit the transfer of sea water is uni-directional upward.

The fresh water transport mechanism persists while there is a difference of salinity (density) between the zones. The entrainment process continually reduces this difference. It may be further reduced by loss of fresh water, by evaporation or freezing. When this difference vanishes, the structure is isohaline and the mechanism fails. However, if the upper zone is progressively refreshed, the halocline and the fresh water transport mechanism will persist.

Salinity Structure and Limits of Zones

From examination of extensive data, Tully (1957) concluded that the zone structure could be accurately delineated by plotting salinity as a function of the logarithm of depth. In this presentation, as illustrated in the last diagram of Fig. 1, the salinity distribution within each zone can be closely approximated by straight line segments. The intersections, D and L, of these segments define the limits of the zones.

ESTUARINE FEATURES OF THE SUB-ARCTIC PACIFIC OCEAN

It is possible to show that these features of estuarine structure occur in the sub-Arctic Pacific Ocean.

Salinity Structure

Figure 2 shows representative salinity structures at Ocean Weather Station "P". There is an *upper zone* of relatively isohaline, low salinity water, less than 33‰, extending to 85 ($\pm$ 15) m depth. Below this is a *halocline* extending to 200 ($\pm$ 50) m depth in which the salinity increases to 33.8 $\pm$ 0.1‰ (the index salinity, S^*). Below this is the *lower zone* in which the salinity increases gradually with depth.

This structure has been observed winter and summer throughout most of the region northward of a sub-Arctic boundary located in the Polar Front. Dodimead (1958a) showed that southward of this boundary the salinity at the lower limit of the halocline became greater than 33.8‰ and a salinity minimum appeared below the halocline (Fig. 3). The halocline structure degrades and finally vanishes in a narrow band where the structure is nearly isohaline (Fig. 4). This also could be regarded as the southern limit of the sub-Arctic region (Tully and Dodimead, 1957). Pending further definition, these may be designated the inner boundary (Fig. 3), and the outer boundary (Fig. 4).

Within the sub-Arctic region, in the vicinity of the central Aleutian Islands, Dodimead (1958b) observed that the zone structure degraded to an almost uniform

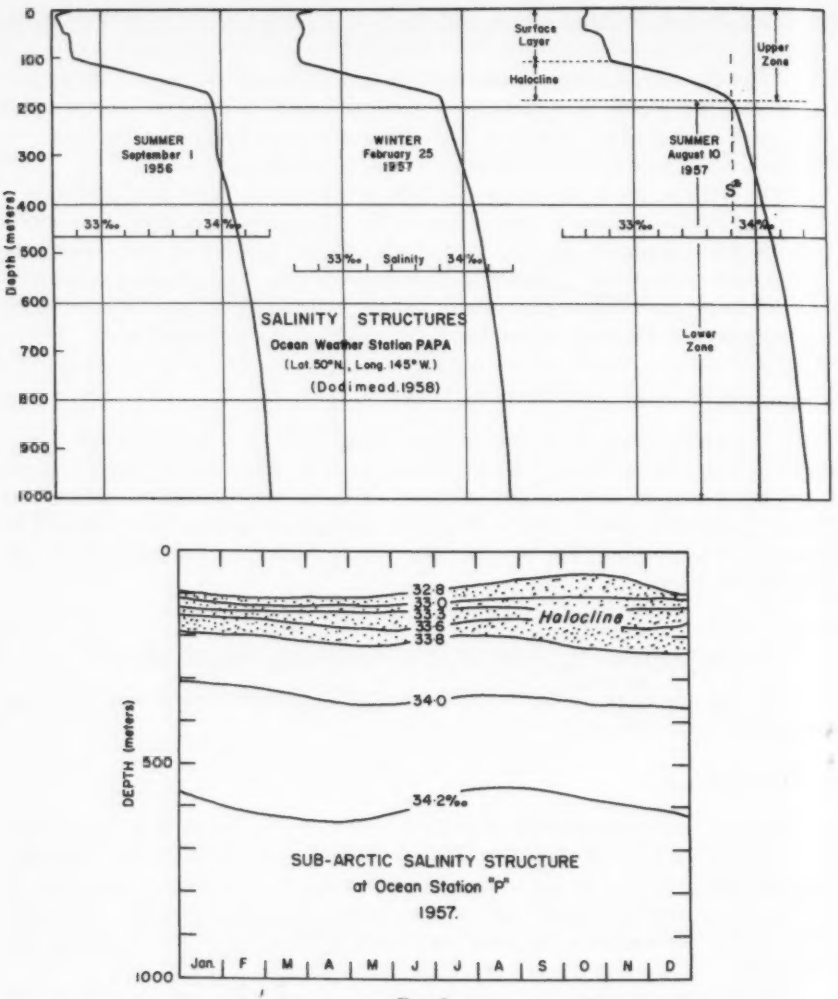


FIG. 2.

gradient, to about 400 m depth. This is attributed to extreme mixing in this locality.

FRESH WATER

Jacobs (1951) has shown that precipitation exceeds evaporation in the sub-Arctic Pacific Ocean and provides a continual, though irregular, source of fresh water in the region (Fig. 5). The low salinity in the upper zone, and the halocline structure, are consequences of this excess input of fresh water. This Figure defines the source region.

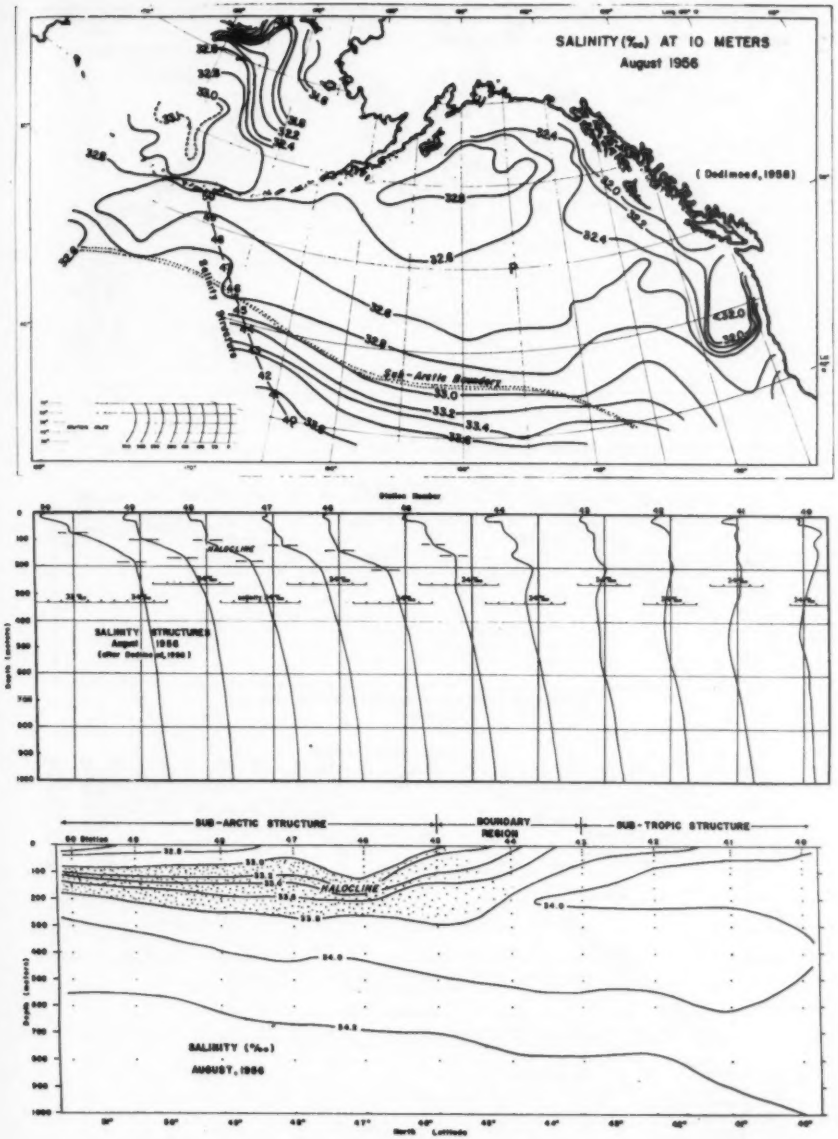


FIG. 3.

Since the limit L of the halocline is the limit of downward transfer of fresh water, and can be identified in a logarithmic plot of the salinity structure, it is possible to compute the amount of fresh water above this limit.

At any position this may be expressed as the fraction C of the depth L that

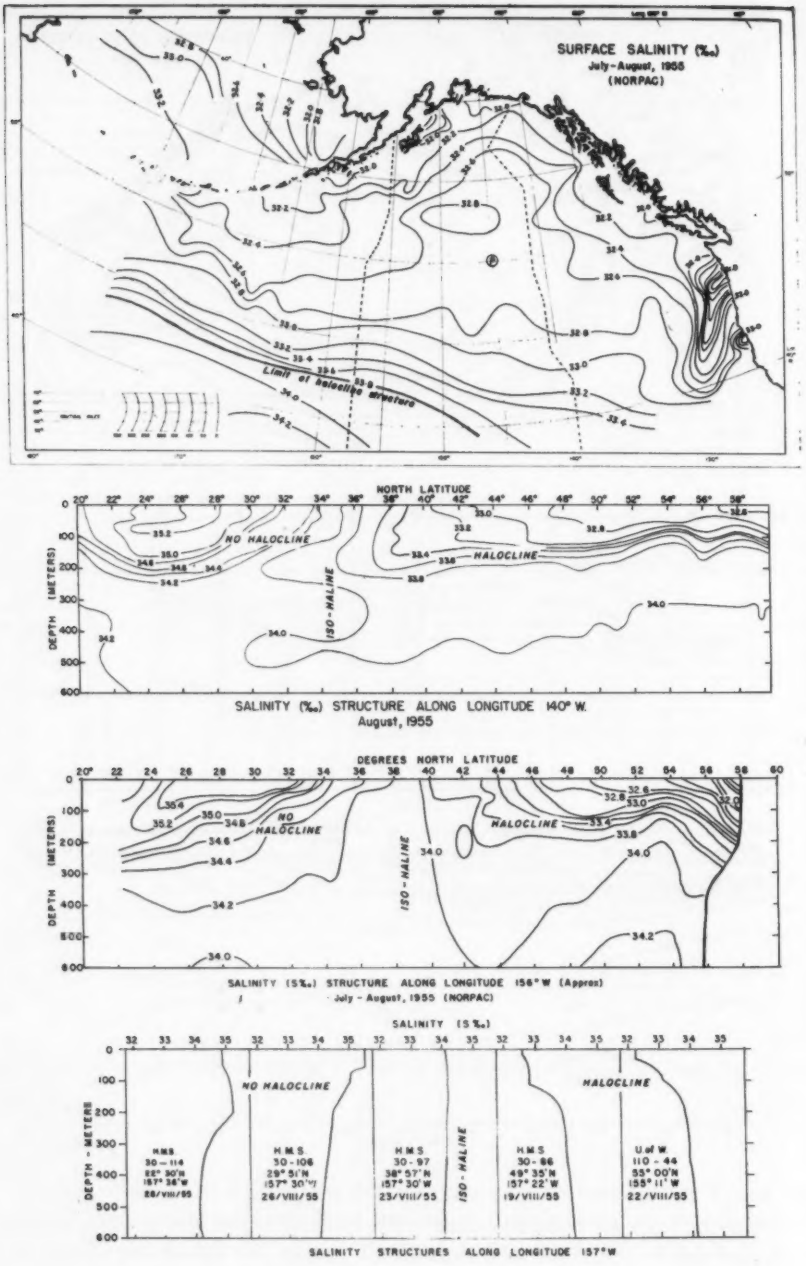

SURFACE SALINITY (‰)
July-August, 1955
(NORPAC)
Limit of halocline structure
NORTH LATITUDE
DEPTH (METERS)
NO HALOCLINE
HALOCLINE
ISO-HALINE
SALINITY (‰) STRUCTURE ALONG LONGITUDE 140° W.
August, 1955
DEGREES NORTH LATITUDE
SALINITY (S ‰) STRUCTURE ALONG LONGITUDE 156° W (Approx)
July - August, 1955 (NORPAC)
SALINITY (S ‰)
H.M.S. 30 — 114 55° 30'N 157° 34'W 28/VIII/55
H.M.S. 30 - 106 29° 51'N 157° 30'W 26/VIII/55
H.M.S. 30 - 97 38° 57'N 157° 30'W 23/VIII/55
H.M.S. 30 - 86 49° 35'N 157° 22'W 19/VIII/55
U of W 110 - 44 55° 00'N 155° 11' W 22/VIII/55
SALINITY STRUCTURES ALONG LONGITUDE 157°W

FIG. 4.

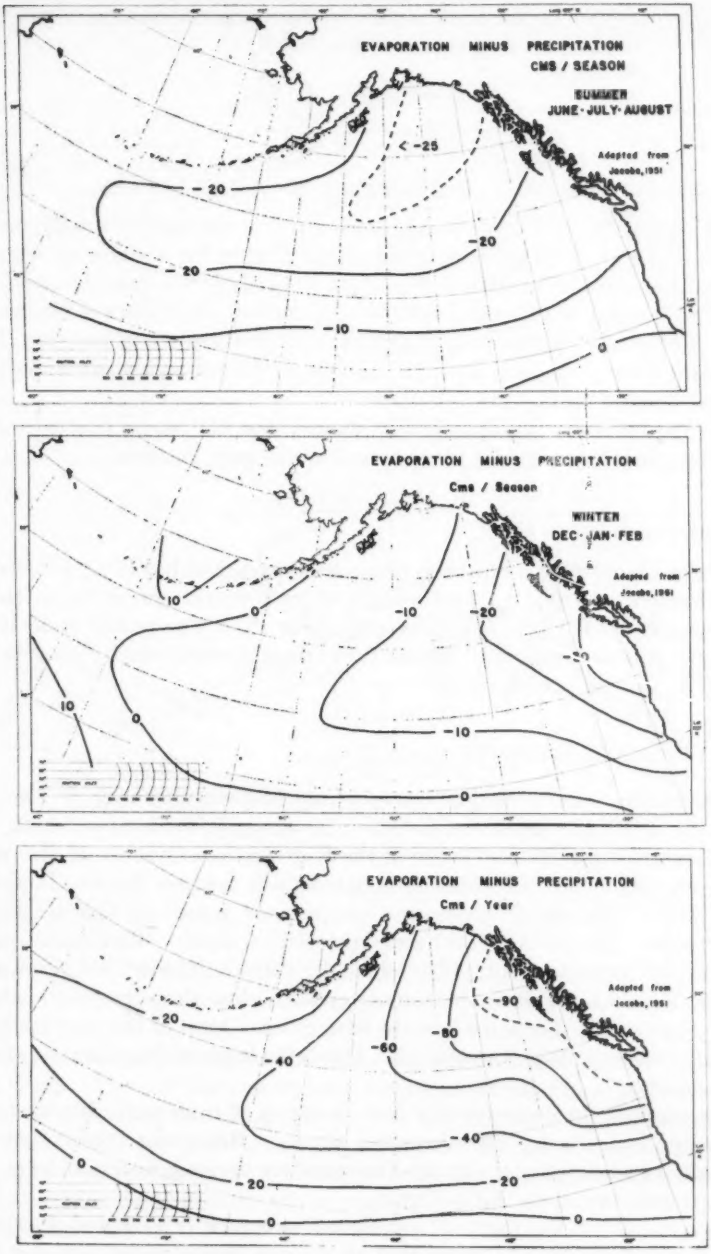

EVAPORATION MINUS PRECIPITATION
CMS / SEASON
SUMMER
JUNE - JULY - AUGUST
Adapted from Jacobs, 1951
< -25
-20
-20
-20
-10
0
EVAPORATION MINUS PRECIPITATION
Cms / Season
WINTER
DEC - JAN - FEB
Adapted from Jacobs, 1951
10
0
-10
-20
-20
10
0
-10
0
EVAPORATION MINUS PRECIPITATION
Cms / Year
Adapted from Jacobs, 1951
< -90
-20
-40
-60
-80
-40
0
-20
-20
0
0

FIG. 5.

would be occupied by the fresh water if it were segregated from water of index salinity S^*, at the limit L of the halocline (Fig. 1):

$$CL = \frac{S^*L - \int_0^L S\,dz}{S^*},$$

where z is the depth taken positive downward.

A representative distribution of fresh water in the eastern sub-Arctic Pacific is shown in Fig. 6. This varies from about 3 m in the vicinity of the salinity maximum in the Gulf of Alaska (Fig. 3 and 4) to about 5 m near the coast.

Two features of this distribution are of interest. The average depth of fresh water is about 3.5 m, the average rate of input is about 0.6 m per year (Fig. 5). Hence the average time of transit through the sub-Arctic region as a whole (Fig. 4) must be about 6 years.

In the earlier study, Tully (1959) showed that the rate of upward transport $-W$ of sea water through the lower limit L of the halocline was:

$$-W = \frac{1-C}{C}Q$$

where C is the fresh water fraction of the upper zone and halocline, $1-C$ is the sea water fraction, and Q is the rate of input of fresh water. From Fig. 6, the fresh water fraction C is 2% to 5%, averaging about 3%. The rate of input is about 0.6 m per year over the area. Hence the average upward velocity must be about 20 ± 10 m per year over the area.

Circulation and Transport

Obviously there are other transport mechanisms operating to create the circulation in the sub-Arctic Pacific Ocean, for example, wind stress (Munk, 1950). In this region, from the confluence of the Kuroshio and Oyashio off the coast of Japan, the warm and cold water move side by side towards America in the West Wind Drift. The surface gradient of temperature across the flow is called the Polar Front. Off the American coast the waters divide. Part turns south to form the California Current. The remainder turns northward and flows around the Gulf of Alaska. This water returns westward, close along the Aleutian Islands and is progressively dissipated into the Bering Sea. Most of this eventually joins the southward flow along Kamchatka. This is the origin of Oyashio and completes the circulation.

Throughout the course of this flow an excess of fresh water is added to the surface and incorporated into the water masses. Hence this mixed water must eventually be transported to the sub-Tropics where the fresh water can be removed by evaporation, or to the Arctic Ocean.

Comparison of the limits of sub-Arctic structure (Fig. 3 and 4) with the circulation pattern (Fig. 7) shows that all the sub-Tropic water, and part of the sub-Arctic water enters the California Current. A small part of the water in the

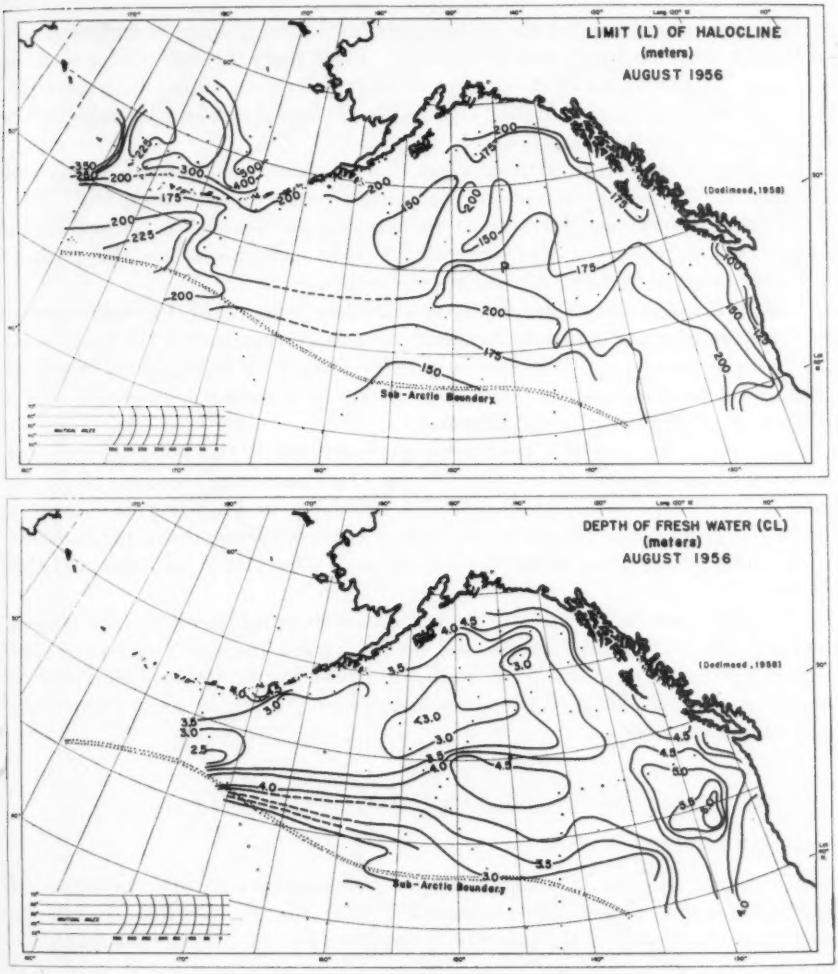


FIG. 6.

Bering Sea is lost through Bering Strait to the Arctic Ocean (Saur *et al.*, 1954; Bloom, 1956). These define two regions of outflow of mixed fresh and sea water.

The NORPAC (1955) data, recorded in the Oceanic Observations of the Pacific (Reid *et al.*, 1959), show that the halocline structure is continuous across the ocean north of the sub-Arctic boundary from Asia to America. Little is known of the lower zone circulation in mid-ocean; but, in the eastern Pacific, between Ocean Weather Station "P" and the Canadian coast, Bennett (1959) has shown a persistent intrusion of deep water. Thus at least one region of deep inflow is recognized.

Figure 6 shows that, in the eastern sub-Arctic, the amount of fresh water is greatest around the North American coast. From there the most direct route of transport, to the region of dissipation in the sub-Tropics, would be southward. However, because of the Alaska Gyral (Fig. 7) the direct southward route is denied to much of this water.

Similar local centres of fresh water concentration occur in the Bering and Okhotsk Seas in gyrals contrary to the shortest routes of dissipation.

Evidently fresh water transport mechanisms are present in the sub-Arctic Pacific Ocean. However, wind-driven and other mechanisms are also present, and determine the paths of flow within the region.

In the estuarine model previously described by Tully (1959) the requirements for net outward transport in the halocline, net inward transport in the lower zone, and a shear zone in the halocline to provide energy for entrainment, were all satisfied by assuming opposite directions of flow in a narrow embayment, and a layer of no-net-transport in the halocline.

However, the required conditions are provided if the volume transport decreases along the path of transport in the lower zone, and increases along the path of transport in the upper zone and halocline, as sea water is entrained. Bennett (1959) showed that there were shear zones in the depths of the halocline (upper 200 m) over most of the Gulf of Alaska. Doe (1955) also observed this feature.

It is therefore concluded that the features of an estuarine region, the salinity structure, the entrainment process, and the fresh water transport mechanism, are realized northward of a sub-Arctic boundary in the Pacific Ocean. Therefore, a comprehensive discussion of the oceanography of the region must include the estuarine model analogy.

SOME FEATURES OF THE MODEL ANALOGY

Origin of the Lower Zone

The index salinity ($S^* = 33.8 \pm 0.1‰$) is remarkably constant northward of the inner boundary proposed by Dodimead (1958a) (Fig. 3). Further, the salinity gradient at the bottom of the halocline is small and less variable in time and space than is the temperature gradient. These features were also noted in coastal estuaries (Tully, 1949; Waldichuk, 1957). Evidently the intruding lower zone is created by a mechanism which allows much less variation in the salinity than in the temperature.

It is suggested that the sub-halocline waters in the eastern sub-Arctic Pacific Ocean may originate in the isohaline region at the outer limit of the sub-Arctic structure (Fig. 4). Northward intrusion, below the halocline, from the direction of this boundary has been observed by Bennett (1959) and Tully *et al.* (1960). The salinity characteristics of sub-halocline water intruding from this source must be constant within small limits regardless of the depth of its origin (at least to 600 m). However, there is a temperature gradient in this boundary region, hence the temperature of the intruding water depends on the depth of its origin.

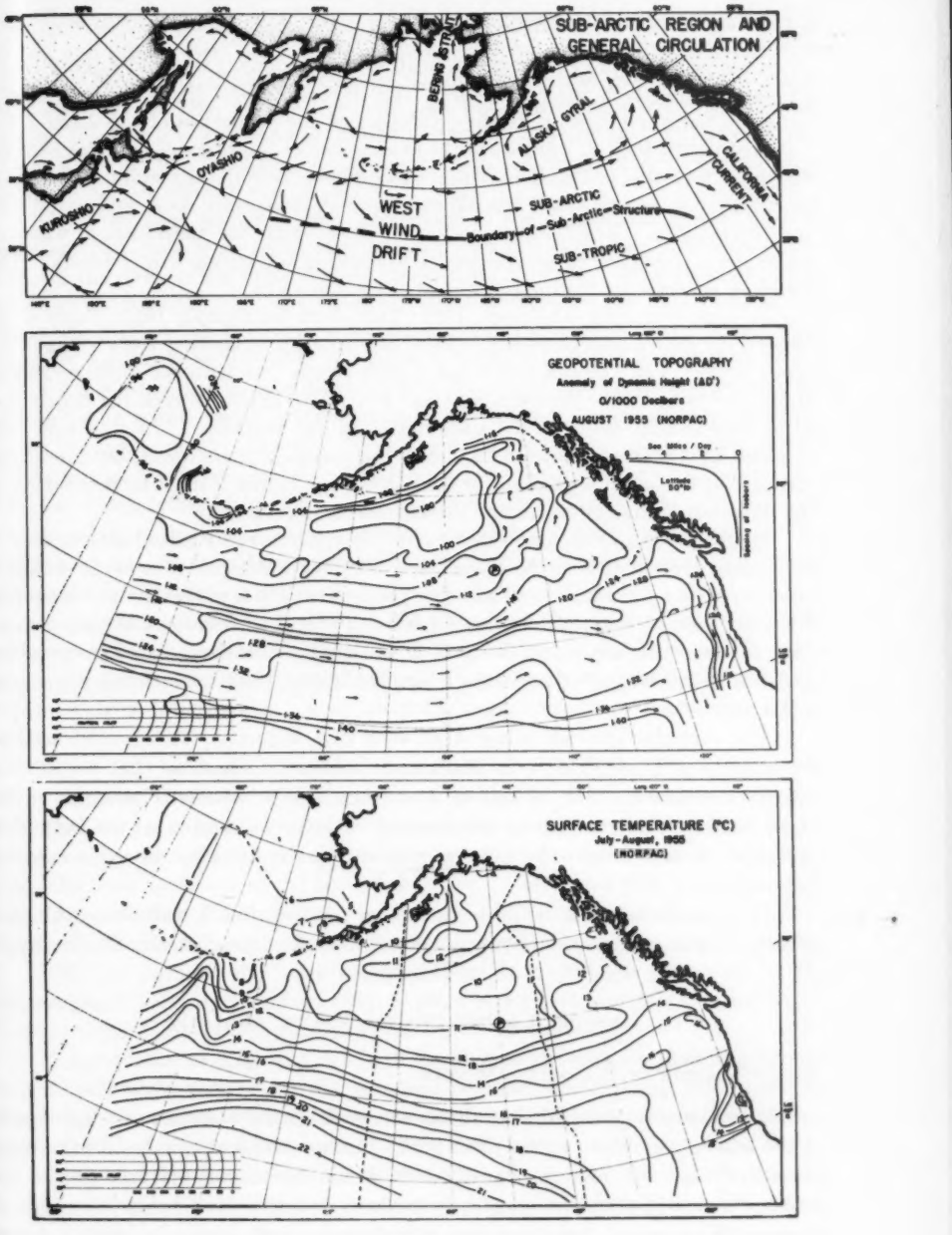

SUB-ARCTIC REGION AND GENERAL CIRCULATION
BERING STR.
ALASKA GYRAL
OYASHIO
KURUSHIO
CALIFORNIA CURRENT
WEST WIND DRIFT
SUB-ARCTIC
Boundary of Sub-Arctic Structure
SUB-TROPIC
GEOPOTENTIAL TOPOGRAPHY
Anomaly of Dynamic Height (ΔD')
D/1000 Decibars
AUGUST 1955 (NORPAC)
SURFACE TEMPERATURE (°C)
July-August, 1955
(NORPAC)

FIG. 7.

Depth of Seasonal Effects

Precipitation and evaporation, heating and cooling, and wind mixing are all surface effects which vary with time. To the extent that these variations penetrate the halocline they affect the constancy of the properties of the water there.

The depth D (Fig. 1 and 2) of the near isohaline upper zone coincides with the depth of the isopycnal layer in winter (Dodimead, 1958a). In summer, when the winds are light, some small haloclines appear in this upper zone, associated with the thermocline. They vanish in winter along with the thermocline, when all structure in the upper zone is destroyed by cooling and strong winter winds. This overturn determines the upper limit D of the halocline.

In earlier studies (Hollister, 1956; Tully and Dodimead, 1957; Tully *et al.*, 1960) have shown that there is a marked annual cycle of heating and cooling in the upper zone. The amplitude decreases with depth and becomes undetectable at about 120 m at Ocean Weather Station "P". This depth exceeds the depth D of wind mixing and includes the upper part of the halocline. In this zone, the seasonal heat exchange cannot be due to the overturn phenomena, because of the presence of the salinity gradient in the halocline. Hence it must be dependent on the downward transfer feature of the entrainment process.

Having recognized that water from the upper zone is mixed downwards in decreasing proportions to the lower limit L of the halocline, it is evident that it must carry its temperature and all other properties with it to this limit. However, the water being transferred downward is being mixed with ever increasing proportions of water originating at the limit L so that the surface induced temperature cycle is masked by variations in the entrained waters, and becomes unrecognizable in the halocline.

The variation of fresh water input with time is small. This is evidenced by the studies of Doe (1955) and Dodimead (1958a) which show that the surface salinity distribution (Fig. 3 and 4) is consistent from winter to summer within about 0.2‰. There is little or no seasonal variation of salinity at the limit D of the upper zone. Hence the salinity gradient in the halocline is not a seasonal function.

It is concluded that the lower limit L of the halocline is well below the limit of recognizable surface-induced seasonal variations in the sub-Arctic Pacific Ocean.

AN APPLICATION OF THE MODEL ANALOGY

Identification of Halocline Water

It has been established that all the sea water in the halocline and upper zone of the sub-Arctic region enters these zones through the lower limit L of the halocline, and that the vertical transfer here is uni-directional upward. Since the salinity is nearly constant on this boundary, and it is well below the limit of recognizable seasonal variations, the intruding sea waters may be identified here by their temperature alone.

Once they are entrained, these primary sea waters are mixed, heated and cooled, and diluted with fresh water. Hence, as they approach the surface their identities become obscured. However, recalling that the entrained sea water constitutes 95 to 98% of the halocline and upper zone, and that the rate of vertical transfer is of the order of 20 ± 10 m per year, it is evident that any change of the water on the inter-zone boundary presages corresponding changes in the shallower waters, despite surface effects.

This inter-zone boundary may be defined in the logarithmic plot of normal oceanographic data from serial observations. In this definition, based on structure, all the data in the halocline and lower zone are used. Minor variations in structure are smoothed. The conclusions are objective. It can be applied in any region where there is a halocline, whether or not the salinity at its lower limit L is constant, e.g. between the inner and outer sub-Arctic limits (Fig. 3 and 4).

Northward of the inner sub-Arctic boundary (Fig. 3) this procedure may be *approximated*, within small limits of error, by plotting the temperature corresponding to the index salinity, 33.80‰. This is permissible because of the constancy of the salinity at this lower limit L. The required temperature is readily determined from a temperature–salinity (T–S) diagram (Helland-Hansen, 1916). The typical relations in Fig. 8 show that the temperature gradient is small in the vicinity of this value. Hence the error associated with normal variation of the index salinity (± 0.1‰) is negligible.

Using the *approximate* technique, the data from the series of quasi-synoptic surveys have been plotted as shown in Fig. 9. In these diagrams there are warm waters (warmer than 6.5°C) in the Polar Front and near the coast (shaded), separated from a cool water (cooler than 4°C) area in mid-ocean and the Gulf of Alaska.

These may be compared to the conventional T–S analysis (Helland-Hansen, 1916) made by Dodimead (1958a) as shown in Fig. 8. Here the water masses in the halocline were classified arbitrarily according to the temperature level in the halocline as shown in the first diagram, and their distribution in the region deduced from the data as shown in the second diagram. Comparing this with the corresponding halocline (temperature on salinity 33.8‰) plot for August 1956 in Fig. 9, it is evident that the interpretations coincide in every important respect.

For this purpose the halocline plot (Fig. 9) is perhaps preferable to the conventional T–S interpretation (Fig. 8) since it requires no arbitrary definitions, and provides single-valued numerical indices of the waters.

The sequence of diagrams in Fig. 9 shows a progressive northward intrusion of relatively warm water (shaded) past the Canadian coast through 1957 and 1958. These may be compared, regardless of season, because the data are everywhere below the level of seasonal influence.

Tully *et al.* (1960) studied this phenomenon and showed that the temperature increase associated with the intrusion extended from the surface to nearly 500 m depth. They depicted the extent and advance of the intrusion by plotting temperature on the isopycnal sheet $\sigma_t = 26.60$ (Fig. 10). In the eastern sub-

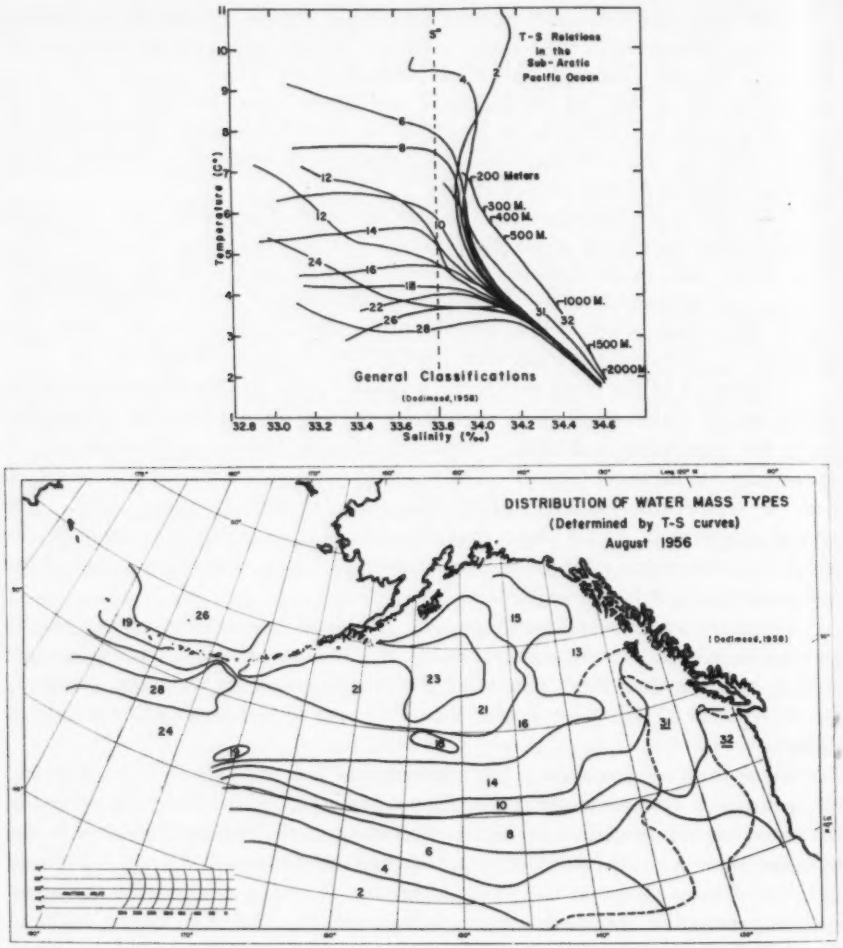


FIG. 8.

Arctic Pacific Ocean this sheet lies everywhere in the halocline. It is close to the lower limit and below seasonal influence near the American coast, and approaches the upper limit in the center of the Gulf of Alaska.

Comparison of Fig. 9 and 10 shows that the halocline and isopycnal analyses coincide in every principal feature. In particular the progressive increase of the northward intrusion of warm water past the Canadian coast through 1957 and 1958 is equally apparent in both analyses. It may be argued that the interpretation in Fig. 9 is the more significant because it defines the features on the inter-zone boundary, a surface of known consistent upward transfer.

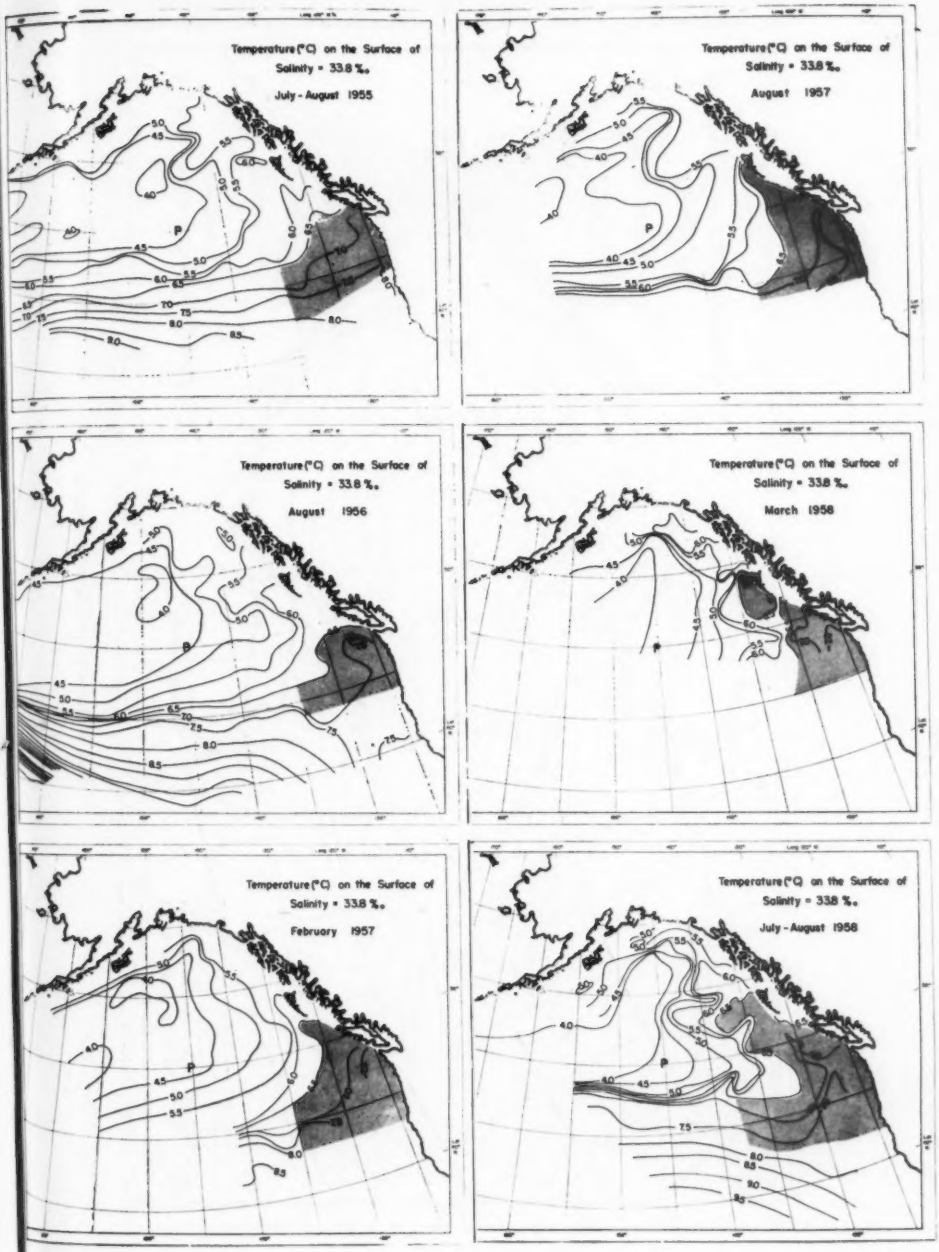

Temperature (°C) on the Surface of Salinity = 33.8 ‰
July - August 1955
Temperature (°C) on the Surface of Salinity = 33.8 ‰
August 1957
Temperature (°C) on the Surface of Salinity = 33.8 ‰
August 1956
Temperature (°C) on the Surface of Salinity = 33.8 ‰
March 1958
Temperature (°C) on the Surface of Salinity = 33.8 ‰
February 1957
Temperature (°C) on the Surface of Salinity = 33.8 ‰
July - August 1958

FIG. 9.

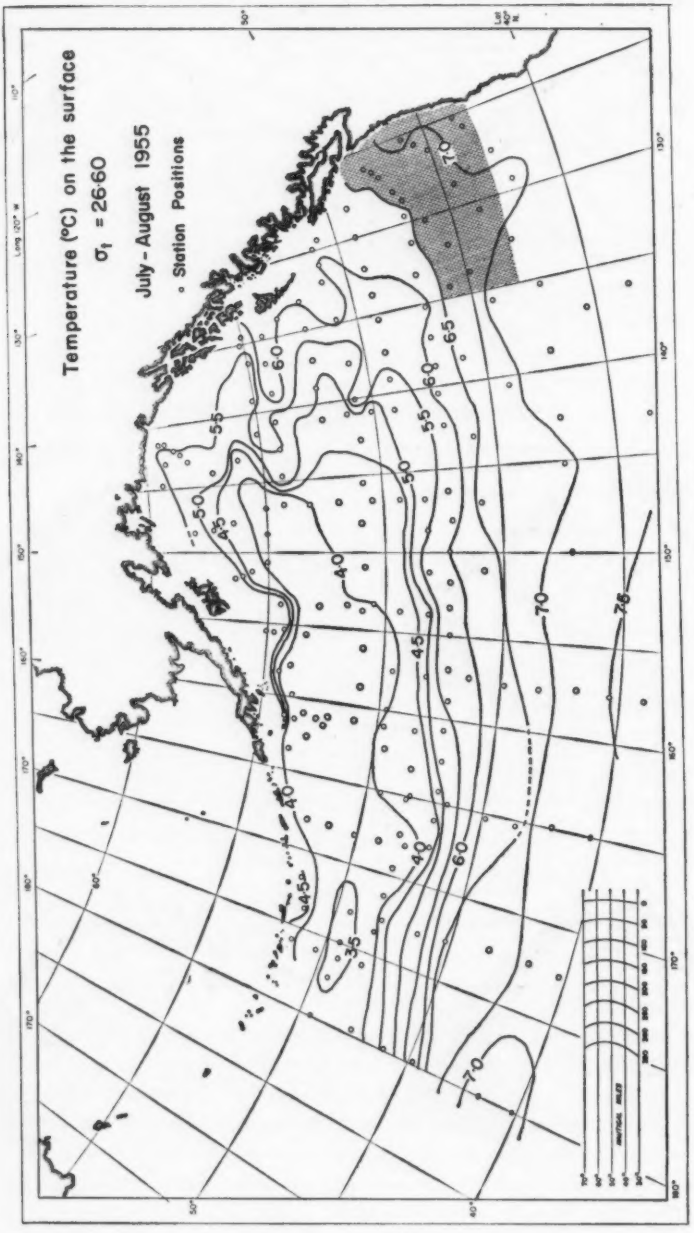


FIG. 10 (cont'd on following pages).

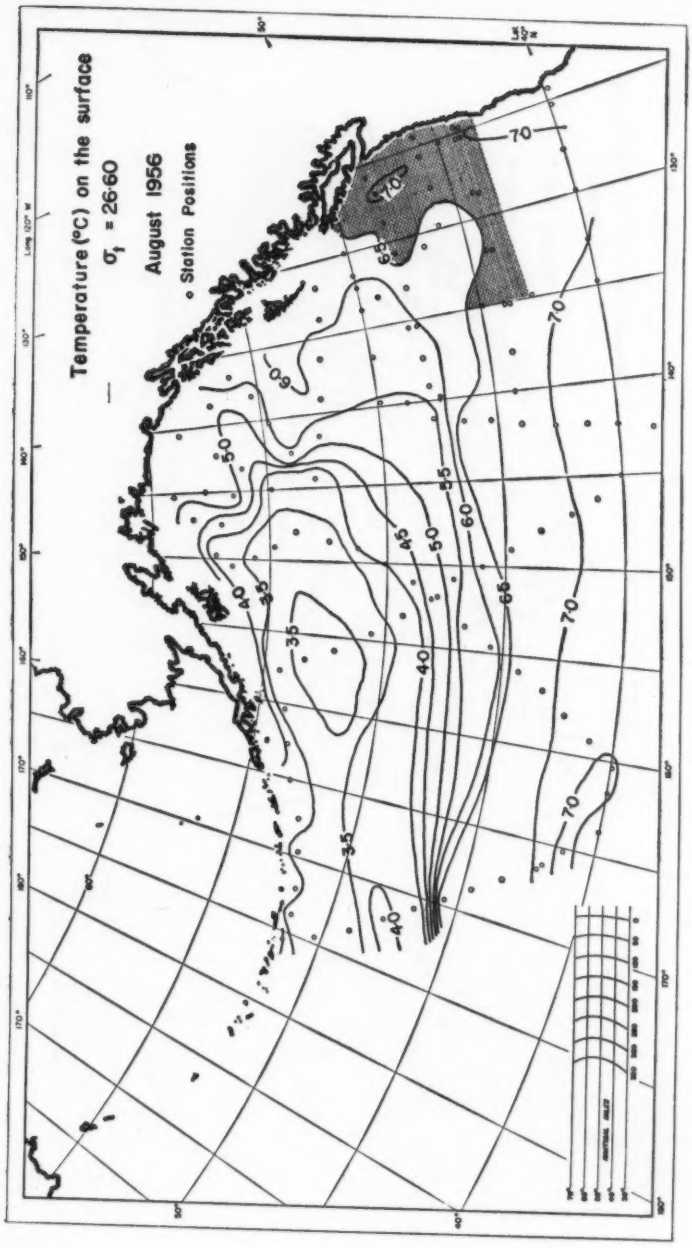

Temperature (°C) on the surface
σ_t = 26·60
August 1956
• Station Positions
Long 120° W
50°
40°
70
65
60
55
50
45
40
35

FIG. 10 (cont'd).

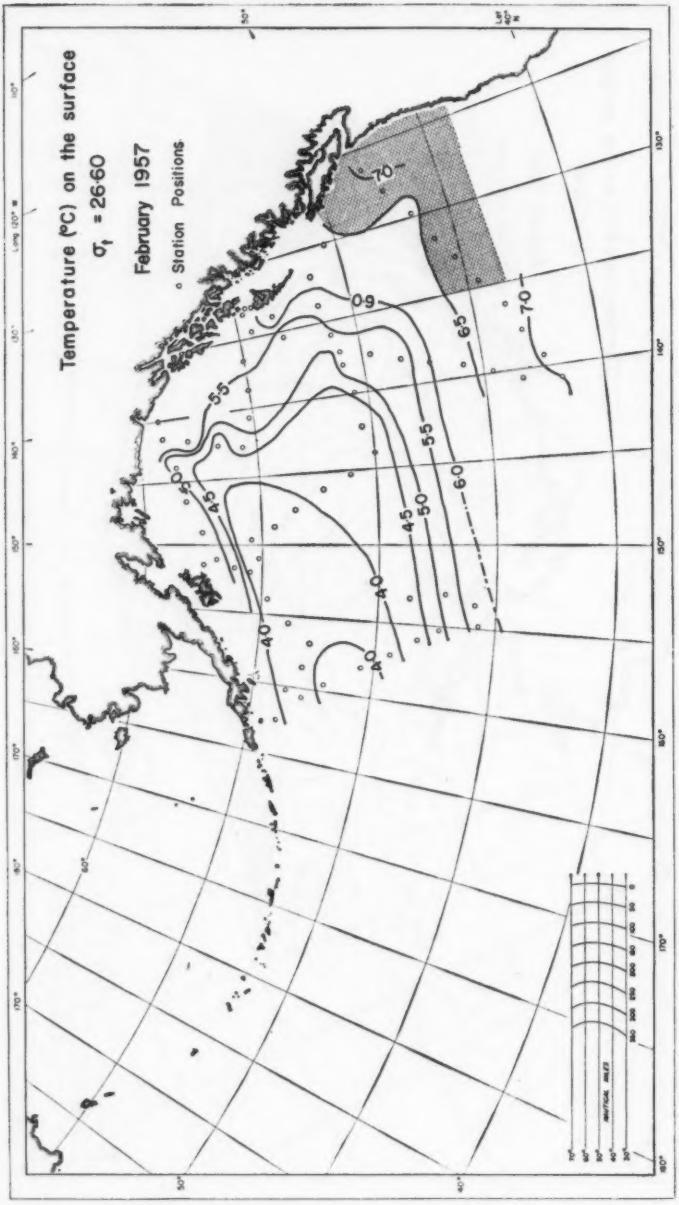

Temperature (°C) on the surface
σ_t = 26·60
February 1957
Station Positions
70
65
60
55
50
45
40
35

FIG. 10 (cont'd).

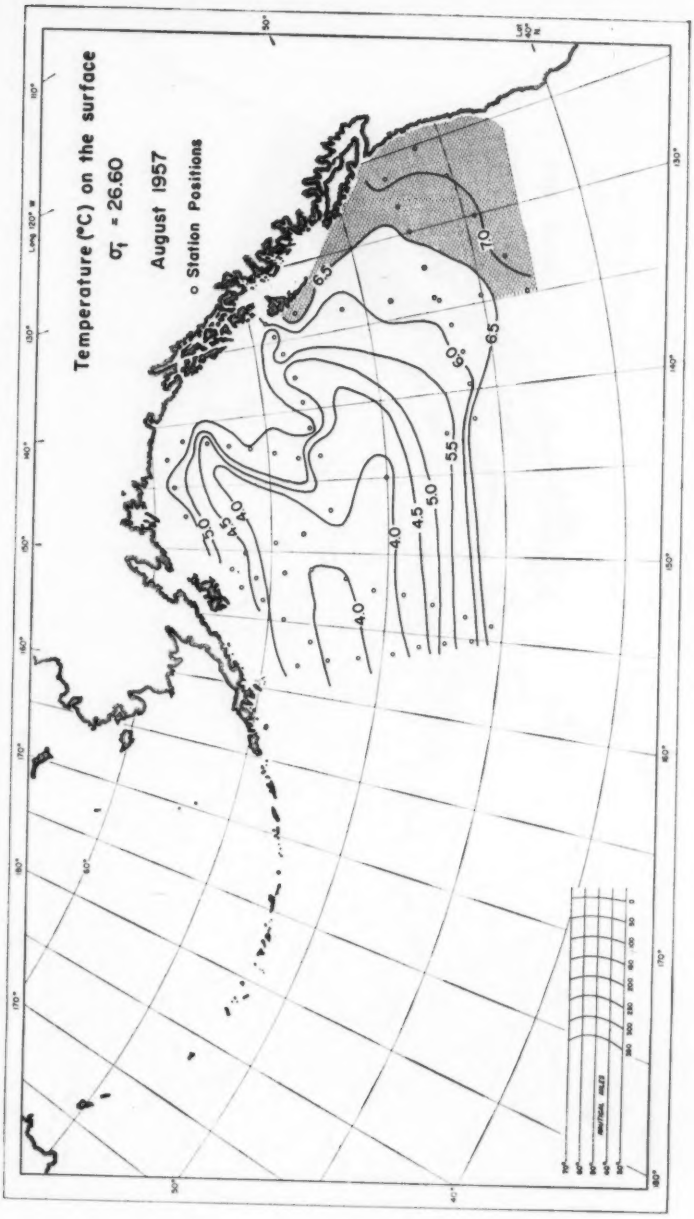

Temperature (°C) on the surface
σ_t = 26.60
August 1957
o Station Positions
4.0
4.5
5.0
5.5
6.0
6.5
7.0

FIG. 10 (cont'd).

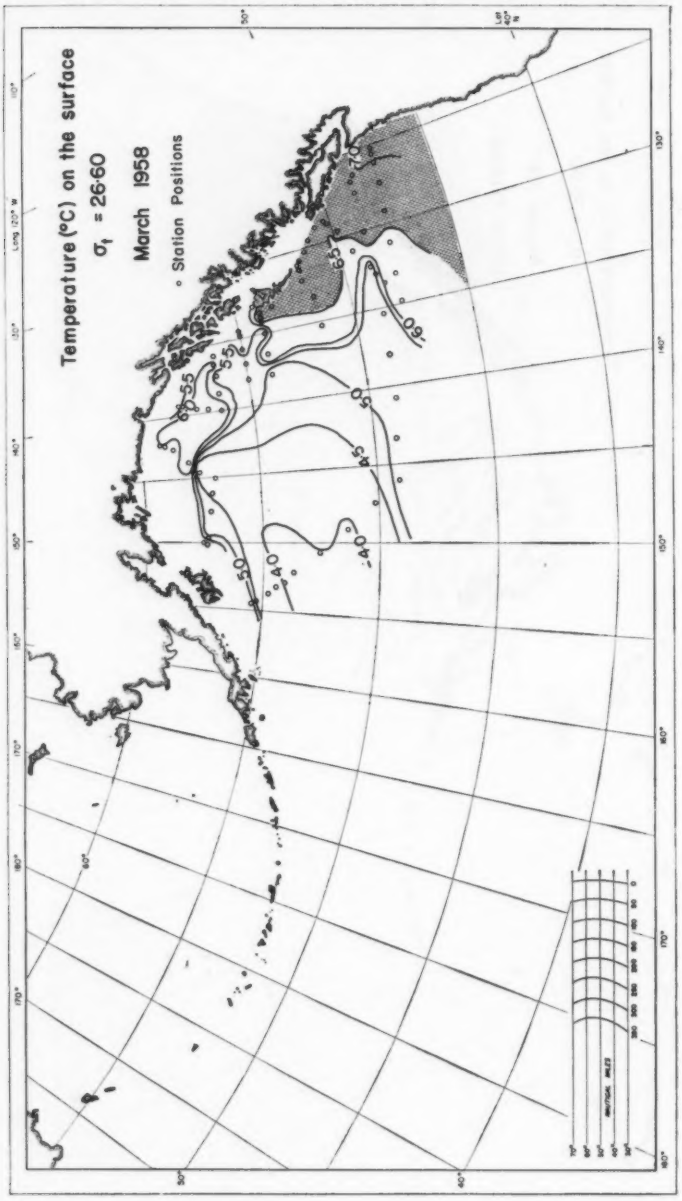

Temperature (°C) on the surface
σ_t = 26·60
March 1958
Station Positions
Long 120° W
.60
.55
.50
.45
.40
.09

FIG. 10 (cont'd).

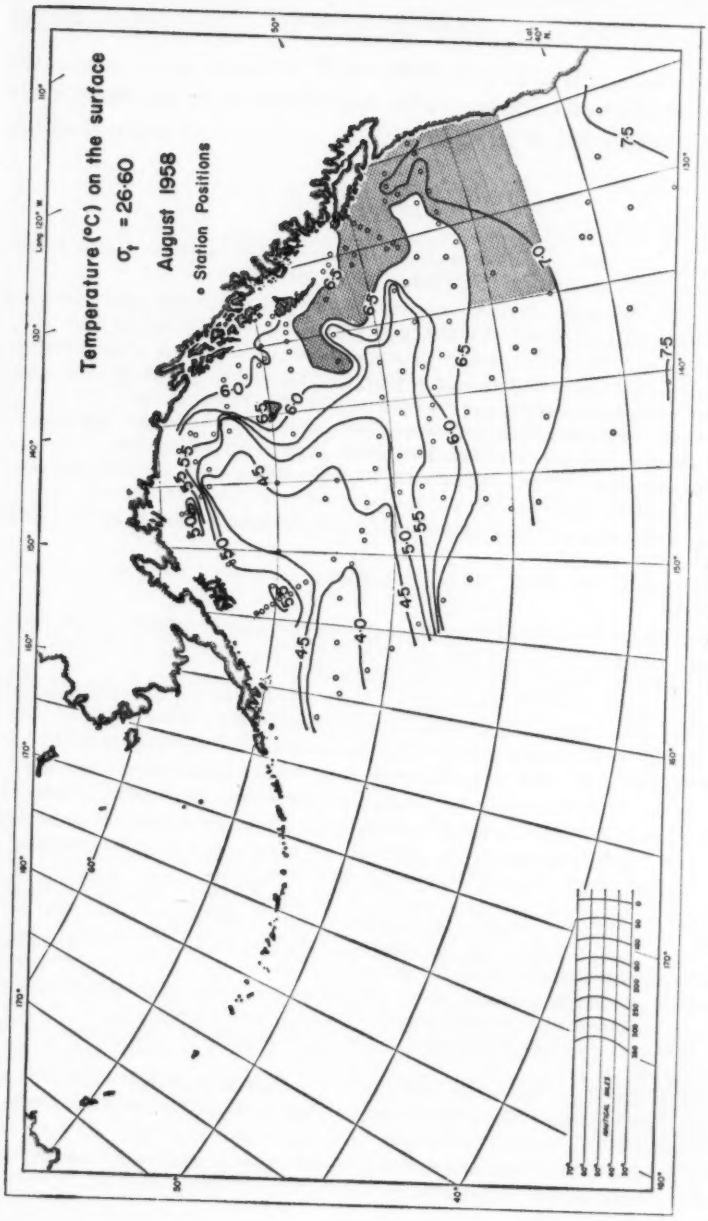

Temperature (°C) on the surface
σ_t = 26·60
August 1958
• Station Positions

FIG. 10 (cont'd).

ACKNOWLEDGMENT

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REFERENCES

BENNETT, E. B. 1959. Some oceanographic features of the northeast Pacific Ocean during August 1955. *J. Fish. Res. Bd. Canada*, **16**(5): 565–633.

BLOOM, G. L. MS 1956. Current, temperature, tide and ice growth measurements, Eastern Bering Strait–Cape Prince of Wales, 1953–1955. United States N.E.L. Rept. 739. 25 pp.

DODIMEAD, A. J. MS 1958a. Report on oceanographic investigations in the northeast Pacific Ocean during August 1956, February 1957, and August 1957. *Fish. Res. Bd. Canada, MS Rept. Series (Oceanographic and Limnological)* No. 20. 14 pp., 35 fig.

1958b. Oceanographic observations in the vicinity of the Aleutian Islands. *Fish. Res. Bd. Canada, Pac. Oceanog. Group*, Bull. 5808. 3 pp., 8 fig. (Unpub.)

DOE, L. A. E. 1955. Offshore waters of the Canadian Pacific coast. *J. Fish. Res. Bd. Canada*, **12**(1): 1–34.

KETCHUM, B. H. 1951. The exchanges of fresh and salt waters in tidal estuaries. *J. Mar. Res.*, **10**(1): 18–38.

HELLAND-HANSEN, B. 1916. Nogen hydrografiske metoder. *Forh. skand. naturf. Möte*, 357–359.

HOLLISTER, H. J. MS 1956. The program of bathythermograph observations at the Canadian Ocean Weather Station "PAPA" (50°00′N, 145°00′W). MS Rept. Fish. Res. Bd. Canada, Pac. Oceanog. Group. 17 pp., 15 fig. (Unpub.)

JACOBS, WOODROW C. 1951. The energy exchange between sea and atmosphere and some of its consequences. *Bull. Scripps Institution of Oceanography*, U. of Calif., **6**(2).

MUNK, W. H. 1950. On the wind-driven ocean circulation. *J. Meteorol.*, **1**(2): 79–93.

REID, J. L., JR, *et al.* 1959. The NORPAC data, Oceanographic observations of the Pacific. University of California Press and University of Tokyo Press, Berkley and Tokyo. (In press).

SAUR, J. F. T., J. P. TULLY AND E. C. LAFOND. 1954. Oceanographic cruise to the Bering and Chukchi Seas. Summer 1949. Part IV. Physical oceanographic studies. Vol. 1. Descriptive report. United States N.E.L. Rept. 416, 27 pp.

SVERDRUP, H. U., M. W. JOHNSON AND R. H. FLEMING. 1942. The oceans, their physics, and general biology. Prentice-Hall, Inc., New York. 1087 pp.

TULLY, J. P. 1949. Oceanography and prediction of pulp mill pollution in Alberni Inlet. *Bull. Fish. Res. Bd. Canada*, No. 83, 169 pp.

1957. Some characteristics of sea water structure. *Proc. Eighth Pac. Sci. Cong.*, 1953. National Research Council, Philippines. Vol. III. pp. 643–663.

1959. On structure, entrainment and transport in estuarine embayments. *J. Mar. Res.* (In press.)

TULLY, J. P., AND A. J. DODIMEAD. MS 1957. Canadian oceanographic research in the northeast Pacific Ocean. MS Rept. Fish. Res. Bd. Canada, Pac. Oceanog. Group. 11 pp. (Unpub.)

TULLY, J. P., A. J. DODIMEAD AND S. TABATA. 1960. An anomalous increase of temperature in the ocean off the Pacific coast of Canada through 1957 and 1958. *J. Fish. Res. Bd. Canada*, **17**(1): 61–80.

WALDICHUK, M. 1957. Physical oceanography of the Strait of Georgia, British Columbia. *Ibid.*, **14**(3): 321–486.

Biochemical Studies on Sockeye Salmon During Spawning Migration.

IX. Fat, Protein and Water in the Major Internal Organs and Cholesterol in the Liver and Gonads of the Standard Fish[1,2]

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ABSTRACT

Absolute changes in fat, protein and water of all major internal organs and free and esterified cholesterol of the liver and gonads of standard male and female sockeye salmon (*Oncorhynchus nerka*) during the 1957 Fraser River spawning migration to Stuart Lake are discussed. The alimentary tract is the major source of fat and protein from the internal organs and the greater part of this reserve is expended in the first 250 miles (403 km) of the river migration. The testes consumed only 0.5% of the energy expended from the body of the standard male while the ovaries consumed 8% of the energy expended from the body of the standard female.

INTRODUCTION

In 1957, a pure race of Fraser River sockeye salmon was sampled (at Lummi Island, Wash., U.S.A.) before the fish entered the river, at Lillooet (250 miles or 403 km distant on the Fraser River in British Columbia), and at the end of a 715-mile (1,152-km) spawning migration (Forfar Creek, B.C.). The data showed that the large number of fish taken (216) and the uniformity of the population permitted an accurate designation of a "standard" sockeye for both sexes (Idler and Tsuyuki, 1958; Idler and Bitners, 1958).

The term "standard" fish is used in this series of investigations to denote the average fish of a pure race in which the majority of the population at a specified location are of approximately the same size and weight as the average. Various organs and tissues undergo significant changes in weight during the spawning migration. The percentage composition and weight of an organ or tissue of the standard fish at any selected location permits the absolute quantity of a component to be calculated. The results are, within reasonable limits, those that could be expected if a proximate analysis could be performed on a fish, the fish returned to the water, and recaptured further upstream.

A previous study (Idler and Bitners, 1959) has shown that the head, skin, bones and tail contributed appreciably more fat energy than did the flesh for the greater part of the river migration. It has been estimated that the fat and protein energy contributed by the viscera, from the time the fish entered the river until death, was very small, 2 to 4%, compared to that contributed by the body (Idler and Clemens, 1959).

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Printed in Canada.

The present investigation was undertaken in order to assess the relative contributions of the major internal organs to the total fat and protein consumption during the river phase of the spawning migration. Liver cholesterol was determined with a view to correlating the results with those previously obtained for flesh and blood plasma (Idler and Tsuyuki, 1958; Idler and Bitners, 1958).

METHODS AND MATERIALS

Twelve groups each of male and female sockeye, totalling 216 fish, were captured in such a manner as to eliminate struggle and stored at −30°C in polyethylene bags (Idler and Tsuyuki, 1958). Protein, water and cholesterol were determined as previously described (Idler and Tsuyuki, 1958; Idler and Bitners, 1958). Fat was determined by a rather extensive extraction procedure because uncooked tissues were used. A 25-g sample was extracted for 16 to 18 hours with 200 ml of methanol in a Soxhlet apparatus. The methanol was replaced by 200 ml of chloroform and the extraction continued for a further 16 to 18 hours. The "oil" was concentrated nearly to dryness in a flash evaporator and the residue taken up in chloroform–methanol (2:1); the non-fat contaminants were then removed as previously described (Folch *et al.*, 1951). The Calorie (Cal) is the large or kilogram-calorie, and fat is taken as equivalent to 9.3 Cal/g and protein to 4.1 Cal/g.

RESULTS AND DISCUSSION

The percentage composition of each tissue is shown in Table I, and the composition of the tissues for a fish of standard length in Table II.

Liver

The liver of both males and females underwent a steady increase in percentage water as the fish proceeded up the river. The liver of both sexes contained 71% water at Lummi Island and 75 to 76% water at Forfar Creek. The changing weight of the liver during the spawning migration modifies these results somewhat. The standard male still showed an absolute increase of liver water between Lummi Island and Forfar Creek from 22.5 to 28 g but the water content of the liver at Lillooet was only 18.5 g. The change in liver water content of the standard female from Lummi Island to Forfar Creek (28.6 to 30.7 g) was not so great as that of the male and the maximum water content (32.6 g) was reached at Lillooet.

The fat content of the liver of both sexes showed a steady decrease from Lummi Island to Forfar Creek and the percentage loss was greater for the male than for the female. The loss of liver fat by the standard male between Lummi Island and Forfar Creek was also greater than that by the standard female. The male lost liver fat in the 250 miles between Lummi Island and Lillooet while the absolute fat content of the female liver remained practically constant. The

standard female liver lost more fat than did that of the standard male between Lillooet and Forfar Creek.

The percentage of protein in the liver of both sexes was substantially constant for the first 250 miles of the spawning migration. The protein content of the male liver then decreased from Lillooet to Forfar Creek considerably more than did that of the female. For the liver of the standard fish, however, the protein content at Forfar Creek was the same as that at Lummi Island for both sexes. However, the male showed a decrease in total liver protein at Lillooet while the female showed some increase at this point.

Alimentary Tract

There was very little change in moisture on a percentage basis for the alimentary tract of either sex in the first 250 miles of the river migration. In the final 465 miles (750 km) there was an increase in its percentage moisture in both sexes. Due to the nearly complete wasting of the tract during the spawning migration, however, in standard fish it had an average water content at Forfar Creek only 17 to 19% of that at Lummi Island.

The percentage of fat in the alimentary tract of both sexes decreased by over 50% from Lummi Island to Forfar Creek. When the decreasing weight of the tract is taken into consideration, the loss of fat from the tract of the standard male and female fish was equal to approximately 90% of the Lummi Island reserves. For the standard male, 82% of the total fat depletion occurred in the first 250 miles as compared with 70% for the female.

The protein content of the alimentary tract of both sexes was greater at Forfar Creek than at Lummi Island on a percentage basis. This is not surprising in view of the extreme loss of fat and water from the tissue.

The loss of protein from the alimentary tract of the standard male and female was of the order of 80% between Lummi Island and Forfar Creek. The loss of protein in the standard fish was analogous to the loss of fat, the male losing 79% and the female 71% of the total protein depleted from the alimentary tract in the first 250 miles.

Kidney

The percentage water in the kidney of both sexes increased by about 3.6% between Lummi Island and Forfar Creek (the corresponding increase for the liver water was about 6%). The standard male showed a trend for kidney water content similar to that for its liver water. There was a small decrease (10%) in total kidney water between Lummi Island and Lillooet and an increase (20%) between Lillooet and Forfar Creek. The kidney water content of the standard female decreased slightly (5%) in the first 250 miles and showed only slight further decrease between Lillooet and Forfar Creek. On a percentage composition basis the kidney protein of both sexes decreased by about 10% during the river migration. The standard male lost no kidney protein, and the standard female lost only about 15% between Lummi Island and Forfar Creek.

TABLE I. Proximate analyses* and cholesterol content* of the major organs of migrating sockeye salmon.

		Location														
		Lummi Island (0 miles)					Lillooet (250 miles)					Forfar Creek (715 miles)				
Components	Sex	Liver	Alimentary tract	Kidney	Ovaries	Testes	Liver	Alimentary tract	Kidney	Ovaries	Testes	Liver	Alimentary tract	Kidney	Ovaries	Testes
Moisture, %	♂	71.2 ±0.13	77.7	77.8	–	80.1	72.9 ±0.28	77.4	79.3	–	80.9	75.1 ±0.21	80.2	80.6	–	80.6
	♀	71.1 ±0.13	78.0	76.1	56.1	–	73.1 ±0.34	77.0	78.6	56.3	–	75.7 ±0.30	79.9	78.9	62.4	–
Fat, %	♂	5.2 ±0.4	6.42 ±0.45	2.27 ±0.23	–	1.64 ±0.06	3.9 ±0.2	5.59 ±0.48	2.58 ±0.03	–	1.76 ±0.06	2.0 ±0.2	2.84 ±0.12	2.43 ±0.06	–	1.95 ±0.12
	♀	4.2 ±0.3	5.58 ±0.28	2.29 ±0.19	14.23 ±0.60	–	3.6 ±0.2	5.05 ±0.28	2.25 ±0.24	14.17 ±0.35	–	2.7 ±0.2	2.93 ±0.05	3.52 ±0.61	10.72 ±0.16	–
Protein N, %	♂	3.08 ±0.12	2.23	2.85	–	2.72	3.03 ±0.03	2.65	2.69	–	2.81	2.55 ±0.01	2.74	2.59	–	3.07
	♀	3.21 ±0.08	2.35	2.91	3.98	–	3.20 ±0.03	2.93	2.70	4.20	–	3.00 ±0.07	2.63	2.66	4.13	–
Free cholesterol, *mg/100 grams*	♂	213.0± 9.1	...	...	–	22.03	190.0± 9.1	...	...	–	20.76	210.0 ±12.7	...	...	–	20.16
	♀	193.0± 3.7	...	...	20.52	–	154.0± 7.1	...	...	21.69	–	190.0± 7.3	...	...	18.75	–
Total cholesterol, *mg/100 grams*	♂	339.0±10.6	...	...	–	41.53	255.0±10.0	...	...	–	29.15	231.0± 9.7	...	...	–	36.36
	♀	262.0± 7.2	...	...	39.54	–	190.0± 9.1	...	...	41.17	–	183.0± 1.8	...	...	43.91	–

*Mean ± standard error. Since the uniformity of the samples has been demonstrated, samples equal in weight were combined for the four groups of each sex and duplicate analyses performed for samples where no statistical analysis is given.

TABLE II. Moisture, fat, protein and cholesterol in the major organs of standard migrating sockeye salmon*.

		Location														
		Lummi Island (0 miles)					Lillooet (250 miles)					Forfar Creek (715 miles)				
Components	Sex	Liver	Alimentary tract	Kidney	Ovaries	Testes	Liver	Alimentary tract	Kidney	Ovaries	Testes	Liver	Alimentary tract	Kidney	Ovaries	Testes
Moisture, *grams*	♂	22.50	70.32	20.23	–	45.26	18.52	23.30	18.48	–	66.34	28.24	13.15	22.65	–	68.83
	♀	28.58	61.07	16.44	44.94	–	32.60	20.17	15.64	77.69	–	30.66	10.31	15.54	185.95	–
Fat, *grams*	♂	1.64	5.81	0.59	–	0.93	0.99	1.68	0.60	–	1.44	0.75	0.47	0.68	–	1.67
	♀	1.69	4.37	0.49	11.40	–	1.61	1.32	0.45	19.55	–	1.09	0.38	0.69	31.95	–
Protein, *grams*	♂	0.97	2.02	0.74	–	1.54	0.77	0.78	0.63	–	2.30	0.96	0.45	0.73	–	2.62
	♀	1.29	1.84	0.63	3.19	–	1.43	0.77	0.54	5.80	–	1.22	0.34	0.52	12.31	–
Free cholesterol, *mg/standard organ*	♂	67.31	...	...	–	12.45	48.26	...	...	–	17.02	78.96	...	...	–	17.22
	♀	77.59	...	...	16.44	–	68.68	...	...	29.93	–	76.95	...	...	55.88	–
Total cholesterol, *mg/standard organ*	♂	107.12	...	...	–	23.46	64.77	...	...	–	23.90	86.86	...	...	–	31.05
	♀	105.32	...	...	31.67	–	84.74	...	...	56.81	–	74.12	...	...	130.85	–

*Absolute amount of constituent for each tissue calculated from the weight of tissue in the fish of standard length (*see* Idler and Tsuyuki, 1958).

Ovaries

The ovaries contained 56% water at the beginning of the migration (as compared to 80% for the testes). On a percentage basis they underwent no change in moisture content during the first 250 miles of the river migration but increased in moisture content by 11% during the last 465 miles. The very large increase in the weight of the ovaries during the river migration resulted in a 73% increase in the ovarian water content of the standard fish between Lummi Island and Lillooet and a 314% increase over the entire river migration.

At Lummi Island the ovaries were rich in fat as compared to the testes. The percentage fat in the ovaries showed no change at Lillooet and then decreased at Forfar Creek. The total ovarian fat of the standard female increased by 72% between Lummi Island and Lillooet and showed an overall increase of 200% over the entire migration period.

The ovaries contained a relatively constant amount of protein nitrogen over the course of the river migration. The total ovarian protein of the standard fish showed a fourfold increase over the course of the river migration due to the increasing weight of the ovaries.

Testes

The percentage of moisture in the testes changed very little during the course of the migration. There was an increase of 47% in the total testicular water of the standard fish during the first 250 miles of the river migration due to increased weight of the testes, but very little increase in water from Lillooet to Forfar Creek.

The fat content of the testes was very low at all times and increased from 1.64% at Lummi Island to 1.95% at Forfar Creek. There was a very small but steady increase in the total testicular fat of the standard fish between Lummi Island and Forfar Creek.

The percentage of protein in the testes increased from 2.72% at Lummi Island to 3.07% at Forfar Creek. Much of the increase in the testicular protein of the standard fish occurred in the first 250 miles (33%), while the increase in the last 465 miles was only about 12%.

Liver Cholesterol

The total cholesterol levels at Lummi Island were greater in the liver of the male (339 mg/100 g) than in the female (262 mg/100 g). Both sexes underwent a decrease of some 25% in total liver cholesterol between Lummi Island and Lillooet. There was a further small decrease in the cholesterol levels of the male between Lillooet and Forfar Creek. The total cholesterol content of the standard male and female liver was almost identical at Lummi Island due to the greater weight of the female liver. This was reflected in the plasma total cholesterol values which were also identical (570 mg/100 ml) for the two sexes at Lummi Island (Idler and Tsuyuki, 1958). However, the very substantial decrease in

total cholesterol in the female plasma between Lillooet and Forfar Creek (490 to 77 mg/100 ml) was not accompanied by a correspondingly large decrease (84 to 74 mg/standard liver) in total liver cholesterol. It appears that there is a time lag between the drop in liver total cholesterol and the lowered plasma total cholesterol levels, and that this is more pronounced in the female.

When the changing weight of the liver is considered both sexes still showed a substantial decrease in total cholesterol from Lummi Island to Lillooet. There was a further small decrease in total liver cholesterol for the female between Lillooet and Forfar Creek and a correspondingly greater increase in that of the male liver during this last phase of the migration. The very significant changes occurring in plasma free cholesterol during the migration (Idler and Tsuyuki, 1958) do not appear to be reflected in liver free cholesterol levels either on a unit weight or standard fish basis.

The free cholesterol content of both male and female livers changed very little over the course of the river migration. There was a decrease in the free cholesterol content of the female livers from 193 to 154 mg/100 g between Lummi Island and Lillooet. The ratio of free to total cholesterol increased for both sexes as the fish moved up the river. The ratio of free to total cholesterol was higher in the female liver at each point during the migration. Free cholesterol represented 63, 74 and 91% of the total cholesterol for the male, and 74, 81 and 100% of the total for the female at Lummi, Lillooet and Forfar Creek, respectively.

The standard male showed a substantial decrease in free cholesterol in the liver between Lummi Island and Lillooet (parallel to the change in total cholesterol between these two points). There was also a substantial increase in free cholesterol between Lillooet and Forfar Creek, again paralleling the changes for total cholesterol between these two points. The standard female also showed a decrease in total cholesterol between Lummi Island and Lillooet, although less than that for the male, and the free cholesterol content of the livers also increased somewhat between Lillooet and Forfar Creek, although again the change was less than for the male. The overall result was that the free cholesterol content of the female liver was essentially the same at Forfar Creek as it was at Lummi Island, while the free cholesterol content of the male liver increased by approximately 17%.

Fat and Protein Energy of Internal Organs

The fat and protein energy content for major tissues of a fish of standard length is shown in Table III.

The testes of the standard fish contained 11 more Calories at Forfar Creek than they did at Lummi Island, while 2,384 Cal disappeared from the body, or 0.47% the total energy expended from the body went for the formation of testes. The testes consumed only 0.33% of the fat and 1.39% of the protein expended from the body.

The ovaries gained 229 Cal of fat and protein over the course of the river migration and accounted for 8.1% of the total energy expended from the body.

TABLE III. Changes in fat and protein energy in major tissues of standard migrating sockeye salmon.

Tissue	Sex	△Calories at Forfar Creek compared to Lummi Island	
		Fat	Protein
Liver	♂	−8.3	−0.4
	♀	−5.6	−0.3
Alimentary tract	♂	−49.7	−6.4
	♀	−37.1	−6.2
Kidney	♂	+0.8	−0.04
	♀	+1.9	−0.5
Gonads	♂	+6.9	+4.4
	♀	+191.1	+37.4
Flesh*	♂	−884	−422
	♀	−1079	−529
Trimmings	♂	−1181	+103
	♀	−1246	+41

*Values included for comparative purposes. For further details see Idler and Bitners, 1959.

The increase of fat in the ovaries was 8.2% of that lost from the body while 7.7% of the decrease in body protein went into the ovaries.

The major internal organs, liver, alimentary tract and kidney of the standard male contributed only 2.7% of the total energy contributed by the body from Lummi Island to Forfar Creek. This was made up of 2.8% of the fat energy and 2.0% of the protein energy expended from the body. The respective values for the standard female were 1.7, 1.8 and 1.0%.

The alimentary tract made by far the greatest contribution of the three major internal organs, contributing 88.2% of the total energy, 87% of the fat energy, and 99% of the protein energy lost from the three major internal organs of the standard male and 90.6, 91.0 and 88.6% respectively from those of the standard female.

The contribution of the alimentary tract relative to the body as a source of energy was greatest in the first 250 miles of the river migration. The standard male expended 77% of the total fat and 79% of the protein used in the river migration in the first 250 miles. The corresponding expenditures for the standard female were 76 and 71%. Thus the alimentary tract of the standard male contributed 3.4% of the total energy contributed from the body, 3.8% of the fat energy, and 2.1% of the protein energy, in the first 250 miles. The corresponding contributions in the standard female were 2.3, 2.3, and 1.9%.

SUMMARY

(1) Previous papers in this series have shown that the flesh was the major source of energy for the spawning migration of sockeye salmon from Lummi Island to the spawning grounds and that the head, skin, bones and tail were the main source of fat. It has been estimated that the viscera contributed only 2 to 4% of the energy obtained from the body and it is now shown that approximately 90% of the viscera energy came from the alimentary tract.

(2) The major portion of the fat and protein was expended from the alimentary tract in the first 250 miles of the 715-mile journey.

(3) The fat and protein energy contributed by the liver between Lummi Island and Forfar Creek was approximately 15% of that supplied by the alimentary tract.

(4) The energy content of the kidney was essentially constant.

(5) The ovaries consumed 8% of the energy expended from the body of the standard female while the testes accounted for only 0.5% of the energy expended from the body of the standard male between Lummi Island and Forfar Creek.

(6) The percentage water increased in all major internal organs between Lummi Island and Forfar Creek. The smallest change in water on a percentage basis occurred in the testes.

(7) It has previously been shown that the plasma total cholesterol level in the female was seven times as high at Lillooet as at Forfar Creek. It is now apparent that there was no significant change in the total cholesterol concentration in the liver between these two locations although there was a 12.5% decrease in cholesterol in the liver of the standard female.

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REFERENCES

FOLCH, J., I. ASCOLI, M. LEES, J. A. MEATH AND F. N. LEBARON. 1951. Preparation of lipide extracts from brain tissue. *J. Biol. Chem.*, **191**: 833–841.

IDLER, D. R., AND I. BITNERS. 1958. Biochemical studies on sockeye salmon during spawning migration. II. Cholesterol, fat, protein and water in the body of the standard fish. *Can. J. Biochem. and Physiol.*, **36**: 793–798.

1959. Biochemical studies on sockeye salmon during spawning migration. V. Cholesterol, fat, protein and water in the body of the standard fish. *J. Fish. Res. Bd. Canada*, **16**: 235–241.

IDLER, D. R., AND W. A. CLEMENS. 1959. The energy expenditures of Fraser River sockeye salmon during migration, spawning and death. *Prog. Rept. Int. Pac. Salmon Fish. Comm.*, 80 pp.

IDLER, D. R., AND H. TSUYUKI. 1958. Biochemical studies on sockeye salmon during spawning migration. I. Physical measurements, plasma cholesterol and electrolyte levels. *Can. J. Biochem. and Physiol.*, 36: 783–791.

NOTES

Pacific Striped Dolphin, *Lagenorhynchus obliquidens*, off the Coast of British Columbia

A large school of Pacific striped dolphins, *Lagenorhynchus obliquidens* (Gill), was encountered 25 miles off the northwest corner of the Queen Charlotte Islands (position: 53°30′N, 133°40′W) on June 16, 1959. The species was positively identified by the author while engaged in pelagic fur seal research aboard the M.V. *Pacific Ocean*. The school numbered at least 1,000, and covered an area of approximately half a square mile.

The known range of *L. obliquidens* extends from Ballenas Bay, Baja California, to Valdez, Alaska. It is commonly seen in coastal temperate waters of California and Oregon, and some have been taken by hand-harpoon in Juan de Fuca Strait. There have been several previous sight records of dolphins presumed to be this species off the coast of British Columbia, but there is only one Canadian specimen record. A skull was found on the beach at Estevan Point, Vancouver Island, in June 1943, and recorded by Cowan and Guiguet (*Murrelet*, **33**(1), 1952).

Previous records show that the species may travel in herds of up to 40 individuals. This record of 1;000 or more in a single school is unique for the Pacific form of *Lagenorhynchus*. The Atlantic counterpart of the Pacific striped dolphin, *L. acutus*, occurs in vast herds of 1500 or more along the coast of Norway (Beddard, A Book of Whales, 1900; Jonsgård and Nordli, *Norwegian Whaling Gazette*, (5), 1952).

The school, as a unit, paced the vessel in a general westerly direction at a speed of 10 knots while individuals or unified small groups of 2 to 8 or 10 indulged their fancies in rapid zigzagging movements, diversions in direction of up to several minutes before rejoining the herd, or impetuous leaps clear of the water to return head foremost or falling sideways with a loud splash. The speed of individuals on occasion must surely have exceeded 20 knots. Seldom did any approach the vessel closer than 20–30 yards and on no occasion did they attempt to play at the bow as is the habit of the Dall porpoise.

Attempts to take specimens using rifles and shotguns were frustrated by the speed and erratic movements of the animals and by their refusal to approach the vessel closely. This is unfortunate, since much remains to be learned about this species. As yet only one complete set of external measurements has appeared in the literature (Scheffer, *American Midland Naturalist*, **44**(3), 1950).

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Three fur seals accompanied the school, apparently delighting in such exhilarating companionship. Such an association of fur seals with dolphins may not be uncommon. In March, 1958, off the coast of California, I saw two fur seals in company with Risso's dolphins, striped dolphins, and right whale dolphins from the M.V. *Trinity*, during the course of pelagic fur seal research.

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Biochemical Studies on Sockeye Salmon During Spawning Migration.

X. Glucose, Total Protein, Non-protein Nitrogen and Amino Acid Nitrogen in Plasma[1]

The levels of cholesterol, steroid hormones and electrolytes in the plasma of Fraser River migrating sockeye salmon (*Oncorhynchus nerka*) have been reported (Idler and Tsuyuki, 1958; Idler *et al.*, 1958). The components reported here were determined since it was felt that their levels might reflect the type of metabolism taking place in the tissues of the fish at various stages during the migration. These components have already been studied in the blood of a group of coho salmon (*O. kisutch*) maturing sexually in an aquarium (MacLeod *et al.*, 1959) to see if any changes which might occur during maturation would parallel those occurring during actual river migration.

The results obtained with the plasma of Fraser River sockeye salmon of the 1957 Stuart Lake run are recorded in Table I. The analyses were performed on portions of the same samples of plasma used for the determination of other blood constituents (Idler and Tsuyuki, 1958; Idler *et al.*, 1958). Details of the methods of capturing the fish and obtaining the blood samples are given in Idler and Tsuyuki's paper. The blood collected from approximately eight fish of the same sex at each check point was pooled to give one sample. Four samples of each sex were obtained at each check point.

TABLE I. Levels of various constituents in the plasma of sockeye salmon during migration (Stuart Lake run, 1957)

Site	Sex	No. of fish	Glucose	Total protein	NPN	Amino acid N
			mg/100 *ml*	%	*mg*/100 *ml*	*mg*/100 *ml*
Lummi Is.	♂	23	206.5 ± 15.5†	6.21 ± .38	36.7 ± 3.4	14.72 ± .43
Lillooet	♂	40	181.3 ± 11.8	5.25 ± .22	29.2 ± 0.4	14.1 ± .40
Forfar Cr.	♂	25	170.5 ± 6.0	4.67 ± .35	39.1 ± 2.22	15.2 ± 1.05
Lummi Is.	♀	35	209.3 ± 19.8	7.24 ± .18	35.0 ± 2.90	14.9 ± 3.8
Lillooet	♀	40	186.3 ± 6.9	6.48 ± .20	29.7 ± .52	14.5 ± .77
Forfar Cr.	♀	55	186.5 ± 5.0	5.45 ± .22	38.9 ± 1.68	15.2 ± .45

†The deviations recorded are average deviations of the means.

The methods used to determine each constituent were the same as those employed in the analysis of plasma obtained from the aquarium-held coho and have been presented in detail elsewhere (MacLeod *et al.*, 1959). Briefly, glucose was determined by the highly specific glucose oxidase procedure, amino acid nitrogen (amino acid N) colorimetrically with β-naphthoquinone-4-sulphonic acid, and total protein and non-protein nitrogen (NPN) by micro-Kjeldahl determinations of total nitrogen in plasma and a protein-free filtrate derived from it.

[1]Part IX of this series appears on pp. 113–122 of this issue of THIS JOURNAL.

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The results shown indicate that the downward trend in the glucose levels in male fish over the migration route is appreciably greater than might be expected from blood dilution, reported to be about 12% for *O. tschawytscha* (Greene, 1926). It is also evident that the pattern of glucose changes was somewhat different in the male and female fish. The marked drop in total protein in both males and females was also greater than might be accounted for by blood dilution. The significant drop in non-protein nitrogen during the early phase of migration and the subsequent rise to values higher than those found initially in the later phase is not unlike the changes observed in the Na^+ level of the flesh of migrating salmon (MacLeod *et al.*, 1958). The NPN drop in the plasma by the time the salmon reached Lillooet, followed by a rise at Forfar Creek farther up the Fraser River, parallels the changes in plasma sulphate and urea in these fish (Idler and Tsuyuki, 1958). That the NPN changes cannot be accounted for by differences in amino acid levels at the various sites is also evident from the results shown.

The results obtained cannot be interpreted readily in terms of present knowledge of the sequence of substrates being utilized as sources of energy in the tissues. The relation of these findings to those obtained on coho maturing in an aquarium have been considered in detail elsewhere (MacLeod *et al.*, 1959).

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REFERENCES

Greene, C. W. 1926. The physiology of spawning migration. *Physiol. Reviews*, **6**: 201–241.

Idler, D. R., and H. Tsuyuki. 1958. Biochemical studies on sockeye salmon during spawning migration. I. Physical measurements, plasma cholesterol and electrolyte levels. *Can. J. Biochem. and Physiol.*, **36**: 783–791.

Idler, D. R., A. P. Ronald and P. J. Schmidt. 1958. Biochemical studies on sockeye salmon during spawning migration. VII. Steroid hormones in plasma. *Ibid.*, **37**: 1227–1238.

MacLeod, R. A., R. E. E. Jonas and J. R. McBride. 1958. Variations in the sodium and potassium content of the muscle tissue of Pacific salmon with particular reference to migration. *Ibid.*, **36**: 1257–1268.

MacLeod, R. A., R. E. E. Jonas and E. Onofrey. 1959. A biochemical study of coho salmon (*Oncorhynchus kisutch*) maturing sexually in an aquarium. *J. Fish. Res. Bd. Canada.* Submitted for publication.